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ADDRESS AT THE ANNUAL CONVENTION AT THE HOTEL PEMBERTON, HULL, MASS., JUNE 19TH, 1895.

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The Constitution provides that the President shall deliver an address at the Annual Convention. It has been the custom to make this address a review of engineering works. I have thought right to depart from this custom. The year has been one of unusual dearth in engineering construction. I feel that it is the time to call attention to the true meaning and position of the profession and the society to which we belong.

Students of primitive society have divided the early development of the human race into ethnical epochs, representing various conditions of savagery and barbarism, and finally culminating in civilization; they recognize three periods of savagery, followed by three periods of barbarism. In the lowest epoch men were little superior to the animals by which they were surrounded. With the use of fire the

second period began. With the invention of the bow and arrow, the most primitive form of projectile, man entered the third period. With pottery, and all that it implies, he passed from savagery to barbarism. The next advance came with the domestication of animals, which gave man another power besides his own physical strength. With the manufacture of iron the last of the barbarous periods was entered. By the invention of the written alphabet the primitive race was promoted from barbarism to civilization.

To us the first, fourth and sixth advances mean more than the others. The use of fire first placed man in a condition very different from that of other animals, giving him a power the uses of which are even yet not fully developed. The domestication of animals was hardly less important, and although where animals suitable for domestication did not exist, tribes were able to pass this period without them, their weakness was apparent when they came in contact with other races whose conditions were not so limited. Finally the invention of a written language made the work of one generation available for its successors and produced historical civilization.

The changes which mark the advances from period to period are all material improvements; in every instance they are characterized by some distinctive physical device which has enabled man either to utilize his own strength better than before, or to increase his power by adding other animate or inanimate force. The race that passed from one period to another acquired resources which it had not had; in the contests which characterized the life of the primitive man, the men of a lower period fell before those who had risen higher. But though the devices were of a purely material character they gave opportunities for mental and moral improvement which alone made further advance possible, till finally the written alphabet culminated in that preservation of knowledge which has made the intellectual efforts of thirty centuries available for ourselves. With the dawn of civilization the ethnical periods have been considered closed; subsequent growth has been the natural advance of civilization marked by the events which make written history.

But there is no reason why the epoch which began with writing should be the last. It only needs a new capacity, radically unlike those which have gone before, to make an epoch in civilization as distinct as those in primitive society. Such new capacity has now been

found; another epoch has begun. Fire, animal strength and written language have in turn advanced men and nations, but the capacity of man has always been limited to his own individual strength and that of the men and animals which he would control. His capacity is no longer so limited; man has now learned to *manufacture power*, and with the manufacture of power a new epoch began. I use the words advisedly; creation, whether of substance or force, is not given to man; manufacture is not creation, but to change inert matter from one form to another in such way as to generate power is to manufacture power.

Furthermore, not only does the manufacture of power mark a new epoch in development, but the change is greater than any which preceded it; greater in its influence on the world; greater in the results which are to come.

The manufacture of power means that wherever needed we can now produce practically unlimited power; whatever the measure of a single machine, that machine can be used to make a greater one; we are no longer limited by animal units, confined by locations of water-falls, nor angered by the uncertain power of wind. Power can be had where it is needed and when it is needed. The manufacture of power has enabled us to concentrate in the hull of a single ship twice as much force as is developed by the whole water power of the Merrimac at Lowell, and this is but a trifle of what may be done.

The new epoch differs from all preceding epochs, in that while they represented successive periods of progress, different races have existed simultaneously in every period of advancement, whereas the new epoch must from its very nature soon become universal. The manufacture of power has given us the means of traversing the entire globe with a regularity and speed which brings all races together, and which must in time remove all differences in capacity. It brings people of all races into contact and by extending knowledge, ends the superstitions and mysteries which have had such influence in the past. It enables man while working in unhealthy districts to spend a portion of his time in places favorable to physical health and bodily vigor and so may end the climatic degeneration of race, which has done so much in history. It is gradually breaking down national divisions, substituting the natural boundaries of convenient government for boundaries based on race and ignorance. It will finally make the human race a single

great whole working intelligently in ways and for ends which we cannot yet understand.

It is not too much to predict that when the full effects of the manufacture of power are realized and the world has passed through the development which the next 10 centuries will see, that the time when man began to manufacture power will be recognized as the division between the ancient and the modern, between ignorance and intelligence, between the national strife which may then be classed as barbarism, and the new civilization, whatever that may then be called.

Great as the new epoch is, it means more to our own profession than to any other. The manufacture of power is the work of the engineer, the inventions which have led to it were made by engineers, in fact it has made possible the profession of the civil engineer.

The new epoch has barely begun. No exact dates can be fixed. Epoch making is not a matter of a single invention; it is the general result which follows. It was not the manufacture of the first earthen pot, but the general introduction of pottery which carried a prehistoric race from savagery to barbarism. It was not the invention of a few letters, but the general use of a written language which took the barbarian into civilization. It was not the invention of the first steam engine, but the general control of the manufacture of power which is now taking mankind into the new civilization. James Watt developed his first steam engine in 1769. The steam engine began to come into general use about the beginning of this century. The 19th century has seen the development of the manufacture of power by steam. The steam engine is still almost the sole representative of manufactured power, but there is no reason why this should continue. Electricity as a conveyer of power has been developed to an extent which may almost be classed with manufactured power. New forms of manufactured power may come at any time, but the introduction of new forms is a comparatively unimportant thing. The great advance came with the ability to manufacture power at all—the method is a secondary thing.

Here, then, we stand at the dawn of a great epoch, of an epoch making greater changes than the world has ever seen; we stand here as members of the profession which is most closely identified with this change and which has most to expect from it. Let us study the lessons which can guide us, in the duties and the responsibilities which are before us.

Let us consider what civil engineering is. The definition, incorporated in the charter of the Institution of Civil Engineers, is familiar to all: "The art of directing the great sources of power in Nature for the use and convenience of man." The Constitution of the American Society of Civil Engineers fixes as a requirement for full membership "the ability to design as well as direct engineering works." The English definition and the American requirement taken together explain what constitutes a civil engineer. His business is to design the works by which the great sources of power in Nature are directed. His works are not built for themselves nor as commemorative monuments; they are made to direct the powers of Nature for the use of man. Every engineering work is built for a special ulterior end; it is a tool to accomplish some specific purpose. Engine is but another name for tool; the business of an engineer relates to tools; a civil engineer must be capable of designing as well as handling tools. The highest development of a tool is an engine which manufactures power. All the great possibilities of our profession come from the existence of such tools.

It is a common error to think of civil engineering as a co-ordinate branch of a general profession with many other branches; to class it with mechanical engineering, with hydraulic engineering, with sanitary engineering, with mining engineering, with electrical engineering, or with any other specific branch. The name of every special branch of engineering has a distinctive meaning; the mechanical engineer deals with machines; the hydraulic engineer, with water; the mining engineer, with mines; the sanitary engineer, with drainage, and the railroad engineer, with railroads. The word "civil" has no such distinctive meaning; it only shows that civil engineering is the work of the citizen and not the work of the soldier. Civil engineering, in its true meaning, embraces every special branch of engineering. The professional limitation which should be applied to the civil engineer is that he must be a man who, in his own department, can design as well as direct; he must have that control over his work which nothing but intelligent knowledge of the subject gives. He may be a railroad builder, he may be a skillful surveyor, he may be a mechanical engineer, or he may follow any other specialty, but whatever he does he must do it, not as a skillful workman, but as one qualified to design. Any man who is thoroughly capable of under-

standing and handling a machine may be called a mechanical engineer, but only he who knows the principles behind that machine so thoroughly that he would be able to design it or to adapt it to a new purpose, whatever that purpose may be, can be classed as a civil engineer. Any skillful sewer-builder and pipe-fitter may claim to be a sanitary engineer, but only the man who approaches his work with the intelligent knowledge of the conditions which sanitation involves can be classed as a civil engineer. Any man who knows how to work a mine may be a mining engineer, but only he who understands why he works his mine as he does can be called a civil engineer. Any well-practiced electrician may be classed as an electrical engineer, but only one whose practical knowledge is based on the intelligent study of electricity can be called a civil engineer. The business of every engineer is to handle tools; the business of the civil engineer, whatever department or specialty he may follow, is to design and build those tools rather than to use them. I use the word tool in its largest sense; you may call it engine if you prefer. Any constructed thing whose principal object is to produce something outside of itself is a tool, whether that tool be a bradawl, a steamship or a railroad. Civil engineering embraces all branches of engineering, but the civil engineer differs from other engineers in that he makes tools rather than uses them. The relation of civil engineering to all other branches is of the broadest kind; no branch of engineering is excluded; the only exclusion is based on the individual qualifications of the men.

The civil engineer is briefly a man who, with knowledge of the forces and materials around him, uses that knowledge in the design and construction of engineering works. His business is to design the tools by which the sources of power in Nature are directed for the use of man. A body of civil engineers should include the choicest minds in every branch of the engineering profession.

Our Constitution provides that a member shall be a civil, military, naval, mining, mechanical, electrical or other professional engineer, an architect or a marine architect, qualified to design as well as to direct engineering works. It would perhaps have been better expressed if it had said that any civil, military, naval, mining, mechanical, electrical, or other professional engineer, architect or marine architect who, with knowledge of the great sources of power in Nature, uses that knowledge in the design and direction of engineering works, is qualified to

be a member. We welcome into our Society all branches of engineering, but not all engineers. We welcome every engineer who applies a knowledge of the powers of Nature to the design and construction of engineering works ; we welcome the architect who uses this knowledge in his designs and constructions, but the architect who treats his profession as a fine art to decorate a construction which he cannot design, belongs elsewhere. Intelligent knowledge of the great powers in Nature is the fundamental requirement for a civil engineer. On this substructure a superstructure of actual design and construction must be built to make the complete professional man.

The civil engineer of the new epoch, the epoch which he is bringing into existence by the manufacture of power, must be an educated man ; in no profession will this be more necessary. The physical laws of power and strength are mathematically exact and admit of no trifling. As the epoch progresses the requirements for each individual will become more complicated. The theologian and the metaphysician may claim that an education based on the laws of matter leaves out the highest part of existence ; the biologist and the physician may claim that matter endowed with life is a higher organism than the inanimate matter with which the engineer has to deal. But, however true these claims, their laws have not the mathematical rigidity, the clear definition and the thorough discipline which mark the laws with which our profession works. The engineer cannot shield himself under doctrines or theories which he accepts but cannot understand. Dealing with accurate definite laws and guided by the corrective touch of physical nature, the education of the engineer will become more necessary, more thorough and more exact than that of any other professional man. This is the training which the civil engineer of the new epoch must have. This knowledge he must have or he must be classed as a workman rather than a professional man.

The civil engineer of the new epoch must sink the individual in the profession. The engineering work of the future must be better work than has ever yet been done. The best work is never done by separate men ; it is only accomplished when professional knowledge so permeates all members of a profession that the work of one is virtually the work of all. The first steps are made by individuals, but the best results come later. The name of Watt will ever be identified with the successful introduction of the steam engine, and nothing should be

allowed to belittle his reputation, but there are 10 000 men to-day, any one of whom can build a far better engine than James Watt ever could. They can do it because they are imbued with all the work the engine-builder has done for more than a century; they do it as members of a profession who are all working together. In the middle ages Gothic cathedrals were built throughout Northern Europe ; they are exquisite works ; no modern architect can approach their beauty; the reason is that the men who built the Gothic cathedrals worked together as members of a guild which was thoroughly imbued with the spirit of building these churches. In no period of the world's history has marine construction had any significance compared with what it has to-day, and it is because the great ship-builders are working together, each having the practical benefit of what they all are doing. They are working together as members of a profession rather than as individuals, and their work is becoming more uniform and more perfect.

The civil engineer of the new epoch must be a specialist. No man can learn to design all the tools by which the powers in Nature are to be directed. The work is too great for one man to master. The best results will only be obtained by concentrating effort in a single line. But though the civil engineer must be a specialist, his specialty must not be of a narrow kind; he must have that general knowledge and training which makes the liberally educated man. The real difference between a liberal education and a special education is that one teaches the student to use his mind and the other gives him information. The civil engineer must have had the mental discipline which qualifies the mind to investigate kindred subjects beyond the limits of his own specialty; his education must be broad enough for this or he will not be a civil engineer. The knowledge of his specialty will be only part of his education; the mental discipline will be more.

And, last, the civil engineer of the new epoch must fill many positions which are now held by men of different training. The knowledge of the tools, both large and small, which men are using, must be the strongest qualifications for their use. Accurate engineering knowledge must succeed commercial guesses. Corporations, both public and private, must be handled as if they were machines, and the men who will so handle them will find their best training in the education which will make the best civil engineers.

Having now considered what should characterize the civil engi-

neer of the new epoch, let us pass from the individual to the profession, from civil engineers to the Society which they have organized. The American Society of Civil Engineers is a national society, though its membership is not restricted even by national boundaries. There are many other engineering societies and associations in our country; some of them are national, some of them are local. A full consideration of the position which our Society should hold in the new epoch must not forget these other societies.

The objects of the American Society of Civil Engineers are defined in the Constitution to be "the advancement of engineering knowledge and practice and the maintenance of a high professional standard among its members," while the means to accomplish this purpose are broadly stated to be intercourse between members, professional papers and a library for professional use.

Intercourse between members is perhaps the most important of all. In no other way can the standard of a profession be raised so well. The man who works alone without measuring himself by others never does his best. The engineer must both measure himself by what others do and let others measure him. The time of cryptograms has gone by; there will be none in the new epoch. Intercourse between members will do more than anything else to fill the requirement of the new epoch and make the work of each engineer the work of the whole profession.

The preparation and publication of professional papers is another duty of the Society. There is an important difference between the papers which must come before a society and those which are published elsewhere. Other professional publications are generally, like architectural monuments, records of what has been done, published for the preservation of those records and not for much more. The fundamental feature of the papers of a professional society, on the other hand, is that, like every engineering work, they are tools. Their work begins when they are read; they are intended to bring out discussions, to compare different views, and in this way to give the knowledge of the profession to all. It is in this line that most development is needed. The papers which are now published in our *Transactions* are, many of them, very good, but the discussions are not what they should be. An author may be best satisfied by the paper which is most perfect in itself, but the paper which brings out the fullest

discussion is the most useful to the Society. We have an endowed prize for a paper worthy of special commendation as a contribution to engineering science; we have another endowed prize for a paper describing in detail accomplished works of construction. There should be a third endowment for a prize for the paper which calls out the best discussion of the year, and this prize should be given without reference to the awards of the other two, so that if the paper which receives the Norman medal also brings out the best discussion it will receive two prizes instead of one.

Our Society has a professional library, but the facilities for using it are far from what they should be and are a poor fulfillment of the constitutional requirement for the establishment of facilities for its use. Every book on an engineering subject ought to be found on our shelves soon after it is published, and engineers should find this library as convenient a workshop as the library of the Bar Association is to members of the bar. It should be open, not only during the daylight hours, but late into the evening, so that the older engineers, who have no time in the day, and the younger men, who have nowhere else to go in the evening, can realize the full benefit of its worth. In a new Society house separate and safe provision for the library must be given special attention.

It will be the duty of our Society to elevate the profession of the civil engineer to the very highest rank among the liberally educated professions. This is a duty of the day rather than a duty of the new epoch. When the new epoch is fully established it will have been done, and the Society will have become the conservator rather than the promoter of the profession.

Furthermore, the main principle of the Society should be the professional principle. It must secure the very best work which can possibly be done among its members—they must not be inventors working alone by themselves. It must teach them that they are members of one profession all working together, until that spirit of professional unity is established in which it becomes impossible for any member of the Society to do bad work.

The Society must work for the profession rather than for the individual; its duties are the advancement of engineering knowledge and practice and the maintenance of a high professional standard. It must not mix itself up with the affairs of individuals; it has no secret

rites nor arbitrary rules; with scales of charges it has nothing to do; it will not demean its members by putting itself on the basis of a labor organization. High professional standards can never be maintained by agreements which restrict the free right of the individual to receive such compensation, large or small, as his own ability has shown he is worth; they can only be maintained by that true professional spirit which sinks the individual in the whole.

The relations which our Society should bear to the other national engineering societies is established by the definition of civil engineering. Our Society should include the choicest minds in every branch of engineering; it must have among its members the leading members of every society which represents an engineering specialty. No other society can have our general range; on the other hand, no other national society can make the same restrictions as to individual requirements. Each of the other societies is devoted to some specific branch of engineering, but the individual qualifications should be comparatively light; it receives into its ranks every engineer working in its specialty, as we receive engineers of every specialty, but not every engineer.

The American Society of Mechanical Engineers accepts as a member any one who is "competent to take responsible charge of work in his department"; it is not necessary that he should be able to design, and while this would be a bad provision for our Society, it is exactly right for the Society of Mechanical Engineers. We take in the educated men of every branch of the profession; each other national society takes in every man who is devoted to the specialty which that society represents. There can be no conflict between those societies and ourselves; it may be hoped that in time every one of our members will belong to at least one of these other societies.

The relation which our Society is to bear to the various local societies is of a different character. These societies are intended to bring together the engineers of the immediate neighborhood in which they are established. Their opportunities for social intercourse and for frequent discussions are necessarily greater than those of a national society. Their requirements for membership should be more liberal than those of any national society. Like our Society they should receive members from every branch of engineering; like the mechanical and other special societies they should admit every one who is qualified to take responsible charge of work in his department. The quali-

fications for a member in the Western Society of Engineers, the Chicago local society, are simply that he must have been engaged for five years in some branch of engineering. It would be an appropriate thing for those local societies which now have it in their title, to drop the "Civil" and let them all become "Societies of Engineers," restricted only by convenience of location.

The relation of our Society to societies of the other classes, may, perhaps, be likened to the three dimensions of space. Our society has a length which is defined by no geographical limits and a breadth which is bounded by no engineering specialties, but its depth is limited by the qualifications of individual men. The other national societies have the same indefinite length that we have, but the breadth is limited to the specialty which characterizes each one of them, while the depth is unlimited as they take in every engineer who follows this specialty. The length of the local societies is confined to the geographical limits which they represent, while the breadth and the depth are both unlimited.

As the national societies all have their quarters in the same city, any engineer residing in or near New York may find all that he needs in one or more of the national societies, but it is hoped that in time every non-resident member will also be a member of one of the local societies.

The differences between our Society and the several other classes of engineering societies are of so radical a nature that it would be a dangerous thing to try in any way to consolidate or unite them. We cannot unite without entirely changing the qualifications for membership. No idea of uniting with the other national societies has ever been suggested. We cannot unite with the various local societies without either so widening the qualifications of our membership that we shall cease to be a society of civil engineers, or so restricting the qualifications of their membership that the ranks of many of them would be destroyed.

But, though we cannot unite with any of the other societies, it is our duty as the leading engineering society of America, and one of the leading societies of the world, to treat all other technical organizations with the same generous kindness and courtesy which should characterize the treatment of gentleman by gentleman, of professional men by each other. The members of the different local organizations

should be welcomed to our headquarters and we should freely exchange our publications with other societies, esteeming it a privilege if we are able to give them more than they give us.

Passing from general considerations to actual work. Engineering tools may, for convenience, be classified on the basis of their approach to the manufacture of power. The first place may be given to the tools which manufacture power; the second place to those which transmute power; the third place to those which transmit power, and, after this, the rank and file of miscellaneous tools may follow.

The only tool in general use for the manufacture of power is the steam engine, but the caloric engine had its field of usefulness, while gas engines and oil engines are doing good work where small installations of power are needed. An engineer who was lately one of our ablest and most active members, Mr. A. M. Wellington, was engaged at the time of his death in the perfection of a thermo-dynamic engine of novel design.

The tools which transmute power are principally two, the water-wheel and the windmill. The water-wheel has been brought to a degree of perfection scarcely equaled by any other tool; the windmill is still a crude and usually a badly made affair. The last year has seen at Niagara, the installation, not yet completed, of the largest water-power plant ever erected.

In tools for the transmission of power the progress of the last few years has far exceeded all that had ever been done before. So long as engineers sought to utilize electricity to manufacture power they failed; but when they adopted it as a means of transmitting power, the results became superb. The dynamo, though logically a tool to transmute power, is practically more properly classed as part of the general tool for electric transmission of power.

Without attempting an exhaustive division, three classes of the more general tools may be mentioned.

The first of these are tools of transportation, of transportation by land, and of transportation by water.

By land, the steam railroad system has become a tool of such magnitude that to many it has seemed as if no man could be a civil engineer unless he were also a railroad builder. The wild extensions built rapidly and carelessly through unsettled territories, or with less rapidity and greater carelessness where not needed in the older dis-

tricts, are nearly done; but an immense work remains in improving terminals, developing better local facilities and generally bringing these great railroad tools into a condition in which they will perform their own duties better and interfere less than now with other work. In a distant part of the world a railroad is building which cannot fail to have a great influence in the new epoch. Twenty-six years ago the American continent was first crossed by a railroad reaching from ocean to ocean; seven years hence the Trans-Siberian railroad will complete a continuous line across the older and greater continent, eastward instead of westward, from the Atlantic to the Pacific. This new railroad, passing around the most populous portion of the globe and the seat of a civilization now farther than any other from the conditions of the new epoch, may do more than any one thing to render that epoch universal. In about a century from its first general introduction manufactured power will have crossed both continents, and by the aid of manufactured power on the ocean it will be possible to make the circuit of the globe in about 40 days. The extension of the electric railroad system, especially in our cities, has been rapid, until now there are in this country not less than 10 000 miles of railroad operated by electricity. In Chicago the newly opened Metropolitan Elevated Railroad, the best designed and most thoroughly constructed road of this kind yet built, uses electric motors.

In transportation by water two very important works belong to this year, one completed, the other as yet no more than considered. The first is the North Sea Ship Canal, which, passing through the northern part of the German Empire, connects the Baltic with the North Sea. The second, of more importance to Americans than any water project started since the conception of the Erie Canal, is the Nicaragua Canal, the completion of which, besides opening a new general waterway, will make the Atlantic coasting fleet available for the coasting service of our whole country. A board of three engineers, all members of this Society, is now in the Isthmus engaged in an investigation which we all hope will justify the early construction of this great work.

The waterway and the boat that navigates it are equally tools of transportation. The advances in marine engineering and especially in the ocean marine have been most marked, the development being both in the manufacture of the hulls, which are now almost invariably built

of steel, and in the development of higher steam pressures through the compounding of engines, until the latest addition to the fleet of full-powered ocean steamers, the *St. Louis*, built at Philadelphia, carries a steam pressure of 200 lbs. and develops her power through two quadruple expansion engines. The advances in lake marine have been almost as great as those in the ocean marine, but all this time our western rivers are navigated by boats which differ little from those which ran upon them 50 years ago. They still have the wooden hulls, the long-stroke high-pressure horizontal engine, the big separate side wheels, and the battery of small boilers; their machinery is a little better than it was at first, the pressures they carry a little higher, but the changes are so slight as to be insignificant. The channels of the principal western rivers are being constantly improved under the direction of the general Government, but as yet no response has been made to these improvements by the radical improvements which ought to come in the boats and their engines. Much is said of the decline of river business—it has declined because land transportation has given better and cheaper facilities. Until the boats on the western rivers make the same advance that other tools of transportation have made, this business must continue to decline.

Another very important class of tools are the sanitary tools. The history of the world is filled with stories of pestilence which could have been avoided entirely by proper attention to drainage and water supply. There is no branch of engineering which is so directly associated with the convenience of man. The larger sanitary tools, unlike the tools of transportation, are generally constructed by public and not by private corporations, and this makes it necessary to build works which the public can understand, where the educated civil engineer may feel that a different thing would be better. The most important work of this kind now in progress is the drainage canal building by the Sanitary District of Chicago, intended to divert water from Lake Michigan to the valley of the Illinois River in sufficient amount to form a clear flowing stream which will not be polluted by the sewage of a great city. This work has now progressed to such an extent that it is expected that the water may be admitted to this new channel before the end of 1896. The work is a very remarkable one, and one which, under the present condition of things, was absolutely necessary to insure the health of the great city of the lakes. But every tool is

likely to be superseded by a better one, and it is somewhat doubtful whether future engineers will consider a tool which washes away the sewage of a city an intelligent solution of a problem of this kind. The canal will be worth all that it costs, but it is not unlikely that another generation will see means adopted to keep the sewage out of the channel which has been built to dispose of it, and will utilize it on the sandy district south of Chicago.

The other classes of tools need be referred to but briefly. Among them are the tools for general commercial uses, such as warehouses and office buildings, in which a decided change has taken place within a very few years. Heavy masonry walls are being discarded in our large cities and skeleton structures of iron and steel are being adopted as the most convenient and economical tools. These buildings must not be confused with the great monumental buildings of the world, they are tools rather than monuments; their construction belongs to the engineer rather than to the architect. They are still marred by inappropriate decorations patterned after masonry construction, but the method of construction has been adopted because it gives economical results, and so with least expenditure of money produces a tool of greatest profit. The durability of oxidizable metal may not be that of masonry; it remains to be proved how durable these buildings are, but as economical structures they are excellent tools. It is interesting to note that in New York City not only is metallic construction being applied to all commercial buildings, but the same methods are being used for the foundations of these buildings that have been proved to be most efficient under great bridges and works recognized as strictly of an engineering character.

Another tool which is about approaching completion and which is being executed under the direction of engineers is the Congressional Library at our national capital. This library building, designed expressly for the purposes of a library, to take care of books and provide for their use, is built on engineering principles, as a tool adapted to its purposes, ornamentation being made subservient to construction and decorated style secondary to use.

We have met at this convention in the oldest part of our country, in the harbor of a great city whose origin distinctively antedates the beginning of the new epoch. Boston was founded 139 years before Watt perfected his steam engine; it existed for nearly 200 years before

the general manufacture of power. In the later centuries of the new epoch it will be regarded as a city of ancient origin. In this community are men whose rank is among the very highest in the design of the highest class of tools, the engines which manufacture power. The leading hydraulic engineers of the country, whose business is to transmute power, have lived here. The Boston local society is the oldest engineering society in America. It is the section of our country which boasts the oldest university, the largest public library and the greatest proportion of educated men; and yet it is, perhaps, more necessary here than in any other part of the world to emphasize the real nature of our profession. I speak as a son of Massachusetts who, though much of his life has been spent elsewhere, has never wholly separated from New England. The ideas of the old epoch were strong; it was hard for the people of Massachusetts to recognize the importance of the civil engineer; the prejudices of the Puritan and of the old-time liberal professions were inherited from the past. There was not always a full conception of the real meaning of the construction of tools. Yankee ingenuity was thought enough to meet all requirements, and men of liberal education justly considered that work which native ingenuity did without training could not be ranked as professional work. Such men did not appreciate the civil engineer because they did not understand his work; they missed the distinctive requirements which make the civil engineer and confounded the profession with men who did not belong to it. Let it now be known distinctly that our profession is one of training and education. The civil engineer is an educated man, whose knowledge of the sources of power in Nature enables him to direct them for the convenience of man.

The tools which we have to build are generally large. The physical man is often a tiny thing beside the work which he has to construct. Nothing illustrates the power of mind over matter better than the work of our profession. Though we deal with matter and our work is of a material kind, it is the mind which has made this matter give forth power, it is the mind which is opening the new epoch, and it is by the training of this mind that the civil engineer must prevail. We are the priests of material development, of the work which enables other men to enjoy the fruits of the great sources of power in Nature, and of the power of mind over matter. We are priests of the new epoch, without superstitions; but, if our profession is to do the good work of which

it is capable, the true spirit of individual immolation which has characterized the devoted priest of all ages must be found among ourselves. The profession can only do its future work by trained minds working together.

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PAINTING OF IRON STRUCTURES EXPOSED TO WEATHER.

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WITH DISCUSSION.

A great deal of thought has been bestowed on the subject of preventing rust on iron structures of all kinds, more particularly those exposed to the action of the elements on land and at sea. It is not intended in this paper to consider iron structures exposed to the action of sea water, but to confine the subject to structures on land.

Much has been said and written in the last few years about the worthlessness of iron oxide as a pigment in paints used for coating iron, and it is even extensively claimed that such a pigment is an active agent in producing rust on metal covered with it. On the other hand it has been said that red lead is beyond question the very best pigment to use, and much favorable comment has been given to paints composed, partially or wholly, either of carbon or its compounds. The objection against iron oxide, stated briefly, is that much of it is manu-

factured from iron by the action of some sulphur compound, and on account of this the oxide is supposed to contain sulphur which acts injuriously on iron. It is said to be an unstable compound, absorbing oxygen readily and conveying it to the metal which it is intended to cover. It is further said that oxide of iron paints are porous like a sponge, and without any action on the part of the ingredients of the paint, permit the air to get at the metal which they are supposed to cover.

It is claimed for red lead that it forms a chemical combination with the oil with which it is mixed, and that when properly applied to iron, it adheres with unusual firmness and makes an absolute covering which is impervious to air and water.

Carbon paints, including asphalts, are said to be chiefly valuable from the fact that the pigment can usually be more finely subdivided than other materials, and the carbon itself is chemically neutral to the iron.

It has been the custom for many years of George S. Morison, M. Am. Soc. C. E., to paint large iron structures with a mixture of pure iron oxide, consisting of a natural iron ore, simply ground without roasting, and pure linseed oil, and the results had been considered very satisfactory. During the past year, however, the officers in charge of one of these bridges became alarmed by the appearance of rust on the structure, both externally and under the paint, and were afraid that the iron oxide in the paint was the direct cause of this rust, owing to the supposed presence of sulphur in the oxide. On account of the supposed general injurious tendency of this class of paint, Mr. Morison decided, therefore, to make some investigations, and the author was instructed to examine the visible condition of the paint and the condition of the metal under the paint on the bridges at the following places:

Cairo,	Nebraska City,	Sioux City,
Memphis,	Plattsmouth,	Minneapolis,
Leavenworth,	Omaha,	Winona,
Rulo,	Blair,	Burlington.

In accordance with the instructions the author made the examination early in December, 1894. Considering the season of the year the weather was unusually favorable, the temperature being such that no discomfort was experienced in the examination of a single structure.

In addition to the structures mentioned above, as many others were examined as were readily accessible in the time allowed for the work.

The course pursued in making the examination was about as follows:

Most of the structures being through bridges, the author usually passed along the floor on the north side examining the end posts inside and out, the vertical posts and diagonals so far as they could be reached from the floor, and the tops of the floor beams and stringers. At each pier the pedestals, floor beams and stringers were carefully examined, and after thus passing over the entire structure along one side, the return trip was made along the south bottom chord in one span, from which the eye-bars of the lower chord, the floor beams and the stringers could be readily inspected; then generally over the top chord of another span, examining at the same time the cross-frames or sway bracing and the lateral bracing. The trip over the top chord was omitted in several instances owing to high winds and wet weather; this omission, however, was not of great importance, inasmuch as the condition of top cords could generally be predicted from the condition of the end posts, all of which were carefully examined on every bridge.

The paint was scraped off in numerous places with an old file ground to a chisel edge, with an angle of about 70°, this kind of scraper proving the most efficient after a number had been tried. The time devoted to the work was not sufficient to examine each individual member; it is believed, however, that no more information could have been gathered in any more prolonged investigation.

The examination was subsequently extended considerably, embracing structures in St. Louis and Chicago, and the total number examined is nearly 60.

The following observations were made at the different bridges in the order in which they were examined:

Cairo Bridge.

The Cairo Bridge was erected in 1888 and 1889, and the painting finished in the latter year. The bridge proper had been given one coat of hot boiled linseed oil, and the approaches one coat of pure iron oxide paint in the shop. The bridge proper was repainted in 1893 with one coat of the same iron oxide paint; the north approach was repainted in 1894 with one coat of the same paint, mixed, however, with lampblack,

to make the color black; and the south approach was repainted in 1894 with a coal tar paint. The bridge, having been so recently repainted, was in very good condition externally, no rust spots being visible anywhere on the surface.

On close examination it was found, notably on the end posts, that there were a number of little spots a little brighter than the surrounding paint, and under these bright spots rust was found. There were also in many places appearances of lumps or blisters under which there was rust; both kinds of spots were easily recognized. The bright spots were most prominent on surfaces exposed to both sunlight and rain, but were likely to occur anywhere, and were found even on the inside of end posts, though not often. The other lumps were usually due either to scale or actual blisters in the paint, indicating that they might have been avoided by a little scraping. In some places it was apparent that no scraping was done at any time, inasmuch as the original mill scale could be scraped off very easily. In such places it was not unusual to find that oil had penetrated under the scale and was often almost liquid, even after five years' exposure. Wherever scale appeared there was likely to be some rust; this was usually of a bright yellow color and was apparently only a thin film which could readily be rubbed off. The little bright spots seemed to be active rust centers, and if these were carefully examined with a magnifying glass, it would probably be found that the paint was cracked and that air and moisture could get in through it.

The paint usually adhered well to the metal and was very tough. The surfaces not exposed to sunlight and rain were in much better condition than the others; this is especially true of the floor system.

The condition of metal under paint here was not examined as carefully as on subsequent bridges for lack of experience as to what to look for. Generally, however, on scraping the paint from spots which indicated rust, the limits of the rust spots were soon reached and bright metal found under the paint.

On the Illinois approach, which had been thoroughly scraped on repainting, there was little visible indication of rust. Several places were scraped which showed the metal to be quite clean.

On the Kentucky approach indications of rust spots were found in the shape of blisters, etc., and on scraping these, rust was found to the limits of the blister, but beyond this the metal was clean.

Memphis Bridge.

The Memphis Bridge received one coat of iron oxide paint in the shops, and two coats of the same paint after erection in 1892.

The author first examined the east approach floor from below. There were some large spots on the lower flange angles of stringers, which, it was thought, were rust on the metal. Upon examination this proved to be drip from the floor above and was outside of paint, and had in no wise affected the metal. The condition of the paint on the floor was excellent, and on surfaces under the floor, where the sun could not penetrate, it was as bright as when put on, and was in most places still soft.

A number of rust spots and blisters appeared on the legs of the tetrapod on the anchorage pier; on the upper part, however, which is more or less protected, these spots did not occur. The anchorage bars were in good condition. The wedge blocks and wedges had a few rust spots on the machined surfaces.

On the bridge proper a few rust spots had developed on the horizontal surfaces, a less number on the upper surface of inclined members and practically none on the vertical surfaces, especially where these were not exposed much to sunshine and rain. On upper side of the inclined end posts and of the portals, the rust spots and blisters of paint were perhaps more numerous than on other inclined members, and on the top chord of the intermediate span, which was the only one examined, these were developed to a somewhat greater extent than on the corresponding end posts. The rust spots were of a dark brown color, and oxidation was in progress.

The floor system throughout the entire bridge, so far as observed, was in as good condition as under the east approach, and the metal under the paint was also generally clean; rust spots were found however.

In general the paint, where not exposed to sun and rain, was about as good as new and not yet dry and hard. Where it is exposed to sun and rain the paint was hard, adhered to the iron very tenaciously, and was exceedingly tough. While there were rust spots visible in a good many places, the bridge on the whole was in very satisfactory condition.

This superstructure was manufactured by several different bridge companies; there was no difference observable, however, in the condition of the paint on the parts made by different firms.

Many of the rust spots were scraped, and beyond the limits of the visible spot there was usually clean metal. At times a thin film of yellowish rust extended some distance beyond the spot, but this was very thin, was readily brushed off, and did not appear active.

Where no rust spots were visible, the metal was usually clean and bright under the paint, although occasional rust spots were found, as, for instance, on lattice bars and webs of stringers.

It was quite noticeable that wherever the surface appeared perfectly smooth there was little likelihood of any rust being found under the paint. On rougher surfaces, or those that were originally scaly, more rust was found. Plates were much smoother than shapes, and also much less rusty under paint. This same feature was noticed at Cairo.

The fence throughout, especially on the channel which forms its top, had a great number of little blisters or scabs, under all of which there was rust of a brown color. These were all open to the atmosphere and were evidently active rust centers; where this eruption did not appear, it was still the rule that rust was found under the paint, but it was generally of a bright yellow color and did not appear active. On scraping the latticing, yellow rust was generally found.

The shop inspector reported that the lacing and Z bars of the fence were pretty rusty before being manufactured; the channels on the top, however, were comparatively clean.

On the west approach viaduct the horizontal members near the ground had rusted somewhat on their upper horizontal surfaces. The vertical and inclined surfaces were in very good condition, and so far as scraped, were generally clean under the paint. The horizontal members higher up were practically free from rust on the surface. The lacing was at times rusted under the paint.

Leavenworth Bridge.

This bridge received a coat of oil in the shop, and two coats of pure iron oxide paint after erection in the summer of 1894.

The external appearance of the paint was exceedingly good. It was faded somewhat where exposed to weather, but was bright and glossy in other places and was in good condition physically everywhere. It was usually tough and adhered very firmly to the iron. It was not thoroughly hardened on any part of the bridge, even where exposed to the sunlight.

Wherever the iron was much pitted, or where scales or blisters were indicated, there was likely to be rust under the paint, and where the metal had a smooth appearance there was none. The shapes showed rust oftener than the plates, although some of the lattice bars of the vertical posts were very badly pitted, and these were rusty under the paint. It was known that these were rusty before leaving the shop, and it was noticeable that the oil which was put on there had soaked into the rust wherever this amounted to anything, and had practically made a paint of it. Under the scale, more particularly on the eye-bars and heavy angles, it was not uncommon to find oil in almost a liquid condition. The outside of the drum was pitted more or less and showed rust under the paint, although this was generally soaked full of oil. On the top chord there was no indication of rust, either on the surface or under the paint. Other members on the top seemed to be in equally good condition. So far as rust was found under paint, it was evidently not in an active condition. While rust was found in spots under paint on almost all kinds of surfaces, it was nevertheless the exception, the rule being that the metal was clean.

After examining the bridge, the author went to the shops of the Missouri Valley Bridge and Iron Works, which were close at hand, and observed the work which was then in process of manufacture. Much of it had a small amount of rust on its surface, in irregular spots and of the same thin, filmy character and yellow color as was noticed both on the Leavenworth and Memphis Bridges. This thin film could be readily wiped off, and some little blisters which had developed could be scraped off. The blisters undoubtedly formed the rust centers, which, after painting, soon broke through and became visible rust spots; and the yellow film of new rust, which could be readily wiped off, was apparently what was to be found under the paint on the surfaces, which otherwise seemed to be in good condition.

Rulo Bridge.

The Rulo Bridge received one coat of oil in the shops, and after erection, two coats of iron oxide paint in 1887. It was repainted in the summer of 1893 with one coat of ~~Cleveland iron oxide~~ iron oxide paint, applied without previously scraping the metal.

The visible condition of the paint on the bridge was excellent, no rust spots being seen anywhere. The paint was generally tough and difficult to remove.

On the top chords of the west deck span there were numerous little lumps indicating blisters, and these were sure indications of rust under the paint. Outside of these blisters rust was not so certain to be found, although it was not always absent. These blisters were, no doubt, caused by earth falling off cars and lying on these chords for a long time. Earth was hauled over the bridge for several years to fill the east trestle. On the vertical plates of the chords there were few of these blisters, and the metal under the paint was generally clean; the same was true of the floor beams and stringers. The cylinder caps had some blisters, which showed rust when scraped; aside from these, the metal under the paint was generally clean. The posts carrying deck spans were also quite free from rust spots under the paint, and in many places where there was some scale on the iron, practically liquid oil was found under this scale.

On the main spans few places were scraped which did not show more or less rust under the paint. On the cover plates of all end posts and portal plates that were examined, there was rust under the paint. Where the exterior was smooth, this was comparatively little; but where rough, there was more. The rust was evidently in spots, as clean places were often met with next to the rust spots. On the inside of posts where the paint was comparatively soft, there was much less rust under the paint than outside, but it was found nevertheless. The web plates of stringers and floor beams were in no better condition than the inclined cover plates, and the horizontal plates on the stiff bottom chord were no worse than the stringers. In stiff lateral bracing the top surface of a particularly smooth angle was quite decidedly rusty under the paint. Every vertical post examined had rust under the paint on the exposed surfaces. Several that were examined on the inside showed clean metal.

The tops of floor beams were in worse condition than any other portion, there being a great deal of rust under the paint. These evidently were not scraped when the bridge was repainted, and here was about the only place where paint could be scraped off easily. The tops of stringers were in much better condition than the tops of floor beams. On one end floor beam a mark painted in the mill with white lead was found, and under this there was no rust. On another floor beam a shop mark in white lead was found, under which there was some rust.

On one end post between the upper and lower flange angles on the side plate a large quantity of oil had collected, was still soft, and had subsequently been painted over. There was rust under this oil.

There was no regularity as to where rust might be expected under paint. It appeared almost everywhere, and clean metal was the exception rather than the rule. Smooth surfaces seemed to be no better than rough ones, and exposed surfaces no worse than those protected.

The bridge had been thoroughly scraped before the first coat of paint had been put on, and the shop inspector reported that the metal in the shop was comparatively clean.

Nebraska City Bridge.

This bridge received a coat of oil before leaving the shop, two coats of iron oxide paint after erection in 1888, and was repainted in 1893. The visible condition of the paint was excellent throughout.

On examining the cylinder piers on the east side, rust was found under paint on the south cylinder, but the north one was clean. These cylinders were originally a part of the Omaha Bridge, and were erected there about the year 1870. They had evidently always been painted with iron oxide paint. The end posts and portals of the deck span were comparatively clean under paint, although now and then a rust spot was encountered. The vertical posts on cylinder piers were also quite free from rust under paint. The top of the upper chord was rusty in spots. Much earth had been hauled over this bridge to fill trestles, and this work was in progress at the time.

The fence throughout the bridge was generally found clean, this applying to angles, tees and lacing, without distinction.

On the main spans the end posts, portals, intermediate posts and eye-bars had few rust spots under paint, and the surfaces of these members were all very smooth. The intermediate posts are built from angles and plates. On the inside of the end posts the paint was still soft, and a few rust spots were found under it. The floor beams and stringers looked well, but more rust was found under the paint than on the posts. The stiff bottom chords had some rust spots under the paint, but were clean on the whole. The top of the cover plate of the upper chord showed more rust under paint than other members. In all classes of members the rust was found to be in spots.

The surface of the metal in this bridge was generally very smooth, and few blisters or lumps were found indicating scale, nor was the metal pitted to any extent.

On a through plate girder a short distance from the bridge, the paint was in good condition, so far as external appearances went. It was built at the same time as the main bridge, painted in the same manner, and undoubtedly repainted at the same time. The metal on the web plates was usually clean; on the cover plates and floor beams, on the contrary, it was usually rusty under paint.

A bridge over the Missouri Pacific Railroad was built in 1888 in connection with the main bridge. It was originally painted next to the iron with a reddish paint, and it was rather difficult to distinguish between this paint and rust. Subsequent coats were of the iron oxide used on the main bridge. There were some spots of rust found under paint in various places.

At no place where rust was found on the Nebraska City Bridge and the smaller structures on the approach was it of any great extent in depth or area. It was generally of a yellowish color, and when exposed by scraping could be easily wiped off, leaving bright iron as heretofore noted.

Plattsmouth Bridge.

The time devoted to this bridge was rather limited. The bridge was completed in 1880, was painted with the usual kind of iron oxide, and is reported to have been painted on an average every two years since with the same iron oxide paint, the last coat being given it in 1893. It looked as if it had not been scraped after the first painting, and as if the paint had been applied on the theory that the larger the quantity, the better the job. The external appearance of the paint was good, except that it was lumpy in appearance from the quantity put on, and re-entrant angles had become curves of appreciable radius. A few rust spots and blisters were visible, principally the latter.

On the west bent of the west approach viaduct the paint adhered well in some places and in others it peeled off very readily, owing, no doubt, to its thickness and the fact that it had never had an opportunity to dry thoroughly. Under the paint the iron was very clean. On the inside of one post a strip of paint 8 ins. in length was peeled off without showing a single rust spot, and the metal looked as bright as if it

had just come from the mill. The stringer webs of the viaduct were in excellent condition under the paint.

On the end posts of the west main span the metal under paint was rusted very badly, the paint was thick and soft, and in places there were large blisters of long standing under which there was rust. Immediately adjoining one of the largest blisters, perfectly clean metal was found under very soft paint. On machine-finished surfaces on the pedestals there was comparatively little rust under paint. The vertical posts were in better condition than the end posts, many being found quite clean under the paint, and those where rust was found were not bad. The flanges and lacing of these posts were generally in worse condition than the backs of channels. The eye-bars were in fair condition, most of them being clean, although some rust was found. On one bar a spot of red paint was discovered next to the metal. This was apparently red lead, and under this there was no rust. The inside of the end posts, so far as examined, was much better than the outside. The top of the floor beams was unusually clean under paint. The upper chord looked well, but on scraping there was dark-colored rust found under the paint. Here the paint adhered to the iron very well, and the rust was such as did not appear at all active. The lateral struts immediately over the stacks of engines were very black, but the paint under soot was in good condition and the iron under it also. Darkness prevented any extensive examination of the top chord, or of anything but main spans.

Wherever rust was developed under the paint on this bridge, it was quite bad, but this could usually be readily traced to blisters or other causes. The paint had evidently been put on too ~~ten~~, thick, and had not dried well, and, therefore, scales and blisters had formed. A blister when once developed is very likely to open somewhere to the atmosphere, and rust is the inevitable result. The sticking qualities seemed not as good with this thick paint as with thinner coats. Wherever the paint was found thoroughly dry, the adherence was all that could be desired.

Union Pacific Bridge, Omaha.

The Omaha bridge received a coat of hot boiled oil before leaving the shop, and two coats of iron oxide paint after erection in 1887. The rust spots that appeared on it were touched up about two years ago, and the entire bridge was repainted with two coats of iron oxide paint

in July, 1894, special pains being taken to scrape the old paint before new was applied.

The external appearance of the paint was excellent. There were neither rust spots, blisters nor daubs of paint visible, it adhered well everywhere, and it was generally smooth.

Under the paint rust was found wherever roughness on the exterior indicated it, and occasionally under the smooth surfaces, but the latter was exceptional.

The tops and sides of end posts and webs of stringers and floor beams were generally clean, rust spots being very rare. The sides of pedestals were equally clean. A few rust spots were found on the under sides of the cover plates of end posts; the inner sides of side plates, however, were clean.

The channels of the intermediate posts were usually found rough, and on these rough surfaces rust was often found. Wherever the surface was smooth, no rust was likely to be found. On the insides of these posts the metal was usually clean. Lattice bars were clean or rusty under paint, as they appeared smooth or rough. The eye-bars were unusually smooth and were clean under paint. The tops of floor beams and stringers, so far as examined, were about equally divided between showing rust and being clean under paint. In a few places where quantities of paint had been spilt, and this was not yet dry, there was usually considerable rust which appeared active.

On the deck spans, of which the east ones were examined more particularly, the top of the upper chord was quite rusty under the paint. This is said to have been very rusty before the recent painting, on account of an accumulation of earth from trains filling the trestle. Webs of stringers and floor beams were clean, as was also the upper side of the lower flange angles. Vertical posts carrying the spans were quite clean under the paint. The cross-struts showed some rust on the upper sides, but this was only in spots. The cylinder piers were examined on both sides of the river. They were apparently painted originally with red iron oxide; this adhered exceedingly well to the iron, but there were also rust spots of the same dry filmy character found under this as elsewhere.

The fence is said to have been quite rusty before the last painting. It was found, however, that where the metal looked smooth, it was clean under the paint. The rust which was found, unless it was under old

scale or heavy paint spots, was in thin yellow films, which could be brushed off readily, leaving the iron in good condition, and this rust was apparently doing no harm.

It was again quite noticeable here that plates were in better condition than the rougher shapes.

Omaha Wagon Bridge.

The wagon bridge at Omaha was originally painted gray, and subsequently of a yellowish color almost white. The yellowish paint was put on in 1893, while the other was applied about 1887. It is not known what this paint was, but presumably it was a white lead, colored. It adhered well to the iron. There were practically no visible rust spots, although the paint looked very dirty.

Under the paint the vertical posts carrying the viaduct were generally clean, the plates being better than the shapes and the horizontal members being more rusty than the vertical ones. The cylinder piers on the edge of the river were scraped in spots and the metal found to be clean. On the main span the cover plate on the end posts showed some rust spots, both inside and outside, though these were not bad. The intermediate posts and eye-bars were generally clean, but rust spots were occasionally found in all localities. On the east end post a red spot was discovered under the paint which was apparently red lead, and under this rust was found.

The rust spots under the paint on this bridge were usually of a dark color as distinguished from the yellow found elsewhere. They were, however, not at all active, being apparently somewhat oil-soaked.

Chicago and Northwestern Plate Girders.

In Council Bluffs, several plate girders belonging to the Chicago and Northwestern Railway were examined.

The Chicago and Northwestern Railway Company uses an iron oxide paint manufactured by the company from iron ore by roasting and grinding and mixing with pure linseed oil. This differs from the paint used by Mr. Morison in that the ore is roasted to drive off sulphur. The oxide of iron used by Mr. Morison contains no sulphur, as will appear later.

On the web plates the peculiar little blisters or eruptions noticed on the fence at Memphis were observed with the usual results, viz.,

that actual rust centers were under these. These little eruptions were not observed on any structure after leaving Memphis. Aside from these the plates seemed to be clean under the paint. The angles and cover plates showed some rust under paint.

East Omaha Draw Bridge.

This bridge was apparently painted with red lead at the shops and subsequently painted gray, and the finishing coat a yellow. The painting was probably done in 1894. The external condition of the paint seemed excellent, although it was beginning to look somewhat dirty. Under the paint the iron was usually clean, though some old rust spots were found on members in almost any position. These spots were again dark and inactive. It was very difficult to scrape off the red lead, and, on this bridge at least, it adhered as well as, if not better than, the best iron oxide so far observed, and it was also quite tough.

Blair Crossing Bridge.

This bridge was given one coat of boiled oil in the shops and two coats of iron oxide paint after erection during the early part of the summer of 1884. The work was done under the direction of the author, and while care was taken to clean the metal thoroughly, to avoid wet or freezing weather, and in general to make a thoroughly good job, it is not believed that the treatment was any better or differed essentially from that of other bridges built by the same chief engineer. The bridge has not been painted since, except in a few spots near the floor.

The end post, upper chord, lateral struts and rods all showed a good many rust spots, most of which were comparatively small individually, but were often gathered in clusters, making it look worse than it really was. There were also, however, some large spots. On the intermediate posts the channels were rustier than the lacing, the latter being in very fair condition. The east side of the intermediate posts and the end posts facing east were apparently worse than the others. The eye-bars and the floor system were quite free from rust. The ends of floor beams were somewhat worse than that portion protected by the ties, which was in exceptionally good condition.

The paint was faded to such an extent that it had somewhat the appearance of stove blacking, except that the color was grayish brown,

its adhesive qualities were exceedingly good, and it was very difficult to scrape it off at all where the original iron had been free from scale. In this respect the paint on this bridge was quite equal to, if not superior to, the red lead on the draw bridge at East Omaha. In the outer surface of the paint on the exposed surfaces, the oil seemed to have entirely disappeared, and there was a thin film of dry paint which could be rubbed off; when this was done the original color was practically restored. In going to the top chord, the author went up the end post, and the prints of his feet over the rivet heads were distinctly visible.

The rust spots were noticeably more numerous on the exposed surfaces than on others, except that on the interior of intermediate posts occasional large scales of rust were found, these being undoubtedly due to the original scale on the inner face of channels. On the east end posts there were a few spots, where paint had evidently been rubbed off when it was still fresh, which showed perfectly clean, bright iron. It is very likely that the original coat of oil put over this iron was still intact and preserving the metal.

As for the condition of the metal under paint, wherever no rust appeared on the surface of plates, including the cover plates of end posts, portals and top chords, the metal was usually clean, and where a rust spot was found it was of a bright yellow color, very thin and apparently not at all active. On the channels of the intermediate posts more rust was found under paint, and this was more common on the flanges than on the back of the channels. The inside of the channels was usually clean, with the exceptions mentioned above. The lacing was quite clean, and in some places where the flanges of a channel were rusty under the paint, the lattice bar immediately adjoining and within 3 ins. of it was perfectly clean under the paint. It was again noticeable that more rust was found under paint on the shapes than on the plates, and the eye-bars again were apt to be found clean. The webs of stringers and floor beams were particularly clean, and the paint on these was hard and very tenacious.

The top chord of the west approach span was somewhat rusty under the paint. The girders leading from the west end of the west approach span to the bank had at one time been painted with asphalt over the iron oxide paint and partially buried in the ground; the metal under this asphalt paint was perfectly clean, although the asphalt had

shriveled up and was peeling off, leaving the iron oxide again exposed to view.

The cylinders under the east approach span were badly rusted on the sheets next to the ground; the upper ones were in much better condition.

Considering the length of time that this paint had been on, it had lasted uncommonly well and preserved the structure admirably, and the existing condition of the sound paint was quite remarkable for its hardness, its adhesive qualities, and at the same time for its toughness. When the bridge is repainted it will be necessary to scrape it thoroughly, but it would be exceedingly unwise to scrape off the paint which now adheres, as no better adhesion can ever be expected. The paint having been on 11 years without rusting the metal, in fact preserving it so well, it is probably safe to leave it on, covering it, however, by a new coat of the same material, which will probably be done soon.

The bridge was wet in the morning, and, on scraping, after wiping off the water as much as possible, it was noticed that water had penetrated into the paint very slightly.

Sioux City Bridge.

This bridge received a coat of boiled oil in the shops and two coats of iron oxide paint after erection early in 1889; it was repainted in June, 1894, with a patent paint, which is an iron oxide of a reddish color and has considerable gloss. How long the gloss will last is not known. From the behavior of some paint of this same kind which was seen subsequently, and which will be described later on, it is believed, however, that it is not likely to crack. It is reported that there were comparatively few rust spots on this bridge before repainting, and that the old paint was thoroughly scraped before the new was applied. It was not scraped off, however, as it was found wherever any scraping was done that it was uniformly very tough and adhered well to the metal. The new paint was also tough, and no blistering was seen.

On the east approach girder the web plates under paint were generally found clean, and so were the upper horizontal surfaces of flange angles, although as everywhere else, a few rust spots were encountered. The cover plates on the top of the girders were also found clean.

The top of the cover plates on the end posts had a few rust spots under paint, although not many. Some were also discovered on the inside of these posts, but they were comparatively rare. On the vertical posts, which were built up of plates and angles, the rust spots under paint were the exception. More rust was found here on the lacing and angles than on the plates. The eye-bars were generally clean. The tops of lateral plates on the pedestals were found rusty, but it was also observed on a rainy day that water did not drain off these readily. The webs of floor beams and stringers were comparatively clean, though rust spots were found occasionally. Some spots were also found on the upper horizontal surface of the lower flange angles. The tops of the upper angles of stringers were generally clean under the paint, and the same was true of the floor beams, although these were a little rustier than the stringers.

On the whole, the condition of the metal under the paint on this bridge was quite as good as any examined. The metal seemed to have been rolled smoother than usual, and it was again noticeable that the plates were much cleaner than shapes, and that vertical and covered surfaces were cleaner than those exposed to sun and rain.

Floyd River Bridge.

The Floyd River Bridge was first painted in 1888 in the same manner and with the same material as the Missouri River Bridge, and was repainted in 1894 the same as the large bridge. The external appearance was very good, except that when painting was done, the water in the river was high and the lower parts of the cylinders were left unpainted.

The water has now gone down, and these cylinders looked badly. The paint was about all gone, but there was little rust. Under the paint the webs of girders were usually found clean. There was some rust on the top of flanges, but the clean surfaces predominated.

Sioux City Elevated Railroad.

This structure was painted with a red oxide of iron when erected, in 1890 or about that time, and has probably not been repainted since.

The cylinders carrying the span over the Chicago, Milwaukee and St. Paul Railroad were scraped, and rust was found on them, this apparently originating from the cracks in the scale, which were produced in bending the plates.

The viaduct proper was quite free from external rust. A large number of posts were scraped, and these were almost uniformly found clean under the paint, though not always.

NORTHERN PACIFIC RAILROAD BRIDGE OVER THE MISSISSIPPI ABOVE ST. ANTHONY'S FALLS.

This bridge was built in the winter of 1883–84. In the shop the surfaces coming in contact and those inaccessible after erection were painted with red lead, and the entire surface then received a coat of the customary iron oxide paint. After erection it was painted with two more coats of the same iron oxide paint. A fire occurred in 1891 which heated the south span and burnt the paint off to a great extent, after which the entire structure was repainted with the same iron oxide paint originally used.

Numerous spots were found on the cover plates of end posts and top chords, which looked as if hot cinders had dropped on these surfaces. It is possible that these spots may have been started in this way, but they were in each case active rust spots, and subsequent observations elsewhere did not confirm the cinder theory. The spots were not noticed on the other members of the bridge, the paint on them being in good condition.

The metal under the paint on the end posts facing south was more rusty than that on those facing north, being quite clean in the latter case. On the top chord rust spots were found under paint where the plates seemed comparatively smooth. The channels of the vertical posts were usually found clean. There was a little rust, however, on the lattice bars; the eye-bars were comparatively clean. The tops of the stiff lower chords were found somewhat rusty; the sides, however, were generally clean. The webs of floor beams and stringers were usually clean, the upper horizontal surfaces occasionally rusty. A mark painted with white lead on the surface of one of the floor beams surrounding the melt number, and evidently done in the mill, was scraped off, and under this white lead the surface was perfectly clean, while all about it, it was rusty. Similar marks were discovered at Rulo with somewhat similar observations. The white lead thus found was brittle and easily scraped, while the oxide of iron adhered firmly to the metal. Here, again, the plates which appeared perfectly smooth on the surface were usually clean, and the rougher shapes were likely to show rust.

Northern Pacific Railroad Bridge over the Mississippi below the Falls.

This bridge was built in 1885. The specifications called for a coat of oil in the mill. It was painted with iron oxide after erection and repainted with the same paint in 1891. On the west approach some rust spots were found on all members, which resembled the spots on the upper bridge, but inasmuch as they were under the floor the theory that they had been caused originally by cinders does not seem to hold. The general condition of the paint was good. Under the paint the metal was generally found to be clean, with the exception of the top of a pedestal angle, which was quite rusty.

Winona Bridge.

This bridge was given a coat of boiled oil in the shop, and after erection in the summer of 1891, received one coat of red lead and then one coat of white lead. The paint was not well applied, it being put on in daubs, and the metal probably not scraped to any great extent.

There were a few rust spots visible in various places, no one place being worse than any other, and these spots were usually blisters due to the inferior adhesion of the paint to the metal, which was undoubtedly caused by dirt or dampness on the metal when the bridge was painted. One intermediate post on the 360-ft. span was particularly noticeable in this respect, the paint throughout its entire length on the face towards the floor being in bad condition and scaled in many places. In this case there was no rust under blisters, and the presence of machine oil on the metal before painting was indicated.

Where the paint was exposed to sunlight the white lead was considerably cracked, and it is believed that these cracks extended through the red lead, although it was a difficult matter to determine this exactly. These cracks were more numerous where paint was thick than where thin.

In many places moisture had entered between vertical surfaces in contact and run out at the bottom, streaking the iron with rust stains. This was particularly noticeable in the cross-frame attachment to posts and in the upper flanges of floor beams.

While the smoke had blackened the white lead on the cross-frames to some extent, it did not seem to have injured it.

On the cover plate of the top chord there were few rust spots and the paint was not cracked to any extent, although on the sides of the chord the cracking was quite marked. It was true generally that vertical surfaces were cracked more than horizontal ones.

On the lower portion of the drum the paint was in worse condition than elsewhere, it being in scales on the edge of the lower flange and to some extent on its top, almost around the entire circle, and under this scale there was a great deal of rust.

The paint itself was universally brittle, even on the inside of the drum and on the insides of stringers or posts, where neither sun nor moisture could get at it. It was more easily scraped off than on any other bridge previously examined, and flew off on scraping like fine iron scale.

Under the paint the metal was found rusty quite often, and there seemed to be no special rule. On the end posts the metal under the paint was found rusty and clean in spots, and on the top chord, where the paint actually looked better, rust spots were more numerous. On the vertical sides of the upper chord the metal was usually clean, and on the eye-bars almost always so. The vertical posts were quite as likely to be rusty as clean anywhere. On the upper surface of the stiff bottom chords the metal was found rusty oftener than clean. The webs of floor beams and stringers looked well and had few cracks in the paint; there were, however, occasional rust spots. The tops of the stringers were quite clean. The usual rule observed elsewhere, that plates were cleaner than shapes, was not so marked in this bridge; in fact, at times the shapes were cleaner than the plates; neither did the position seem to have affected the amount of rust. A pedestal plate which was scraped was found unusually clean, and a floor beam web on the same pier, rusty.

While rust was quite general, it was not of a dangerous character, being the usual thin yellow film easily scraped off.

Burlington Bridge.

This bridge was given one coat of the usual iron oxide paint in the shop, and after erection, in 1891, it received two coats of the same paint. Not much scraping was done in the field.

The plate girders on the west end showed very little rust, although the paint was faded. On scraping, however, rust was found on all web

plates, with one exception; this one was perfectly clean on one side, and on the other side, exactly opposite the clean place, it was rusty. The plates facing south, and consequently exposed to sunlight, were no worse than those entirely protected from the sun. The upper surfaces of flange angles were comparatively clean; in fact, better than the plates.

On the bridge proper, rust was visible on almost all external surfaces, the end posts, portals and top chords being worse than other places. The surface of the metal in this bridge seemed unusually rough, and the perfectly smooth surfaces quite common elsewhere were practically absent. It looked as if this iron had been quite rusty before being manufactured in the shop, or else there was a great deal of scale on it, or possibly a combination of both.

The top of the north stringer in the south track was in worse condition than any other part of the bridge. Here there was scale almost everywhere between ties, and in many places it is no exaggeration to say that this was $\frac{1}{8}$ in. thick, and required a chisel to remove it. This condition is explained by the fact that refrigerator cars east bound drip salt water on the track, and, of course, to the stringer below. The tops of the remaining three lines of stringers were comparatively very clean.

The guard angles were practically devoid of paint and rusty. The north one of the south track was the worst and was covered with scale.

The visible rust spots on the bridge were mostly in the shape of well-developed blisters and of considerable size. It was quite often noticed that under some of these blisters the metal was perfectly clean, the blisters in this case, however, usually cracking in a great many places and indicating that the paint had never adhered to the metal. Probably the surface was covered with machine oil when the paint was first applied, thus preserving the iron but at the same time making it impossible for the paint to stick.

As for the metal under the paint, rust was found pretty generally on cover plates, side plates and angles on the exterior of the end posts. On the inside the metal was cleaner, but rust spots were still readily found. The upper surface of the bottom chord and the outside of intermediate posts and struts all showed more or less rust under the paint. The eye-bars were in much better condition and were usually found clean.

Quite a large number of white mill paint marks were found on this work, and on scraping, clean metal was found under them, while under the other paint the metal was apt to be rusty. The white paint here was brittle and easily scraped off. The iron-clad, on the other hand, adhered very firmly and was very tough.

On the drum, the web plates were surprisingly clean under the paint, the only rust of any extent being found on the north side. As the draw is reversible, this side does not necessarily remain to the north at all times. The flange angles were also in pretty good condition, and the scale found on them at Winona was entirely absent here. On the inside of the drum the struts were usually clean. The web plates of the stringers over the drum were also quite clean, though occasionally a rust spot was found. The cross-frame angles, however, were quite rusty under the paint.

The floor beams and stringers, except on top, were fairly clean, as were also the upper surfaces of the lower flange angles. On the web plate of one floor beam rust was found under the paint in streaks running horizontally, and between these streaks the metal was perfectly clean and bright.

The pimply appearance noticed on the fence at Memphis was quite apparent on this bridge, especially on the top chord. The top chord, so far as examined, was rustier than any other portion of the structure, it having occasional spots 1 ft. square where the paint was all gone. The little eruptions, as at Memphis, were open and active rust centers, and only needed a little time to develop into large spots. The sides of the chords were again comparatively free from rust spots, though they were by no means absent.

Plates in this bridge seemed to be rougher than shapes, and usually there was more rust found under the paint on plates than on shapes. When, however, a perfectly smooth spot was noticed it was quite sure to have perfectly clean metal under the paint. The outlines of old scale could readily be traced on the plates, and under this scale it was almost always rusty. The intermediate posts, made of channels, were more commonly found clean under the paint than rusty. The paint on the tops of the stringers not affected by scale was in pretty good condition, and the metal under it was fairly clean.

The external appearance of this bridge was not as good as that of the Blair Bridge.

The examination as first planned ended here. From the information obtained it was thought best, however, to extend it to a number of structures recently built by Mr. Morison in the vicinity of St. Louis. This was done in January, and, as before, such other structures were examined as could readily be visited. The investigation was further extended subsequently to a number of Chicago structures.

Alton Bridge.

The bridge over the Mississippi at Alton received one coat of iron oxide paint in the shop before shipment, the latter part of 1893, and another coat of the same paint after erection early in 1894. The structure was examined in all sorts of places, and rust was generally found under the paint. The rust, however, was not bad, being mostly of a thin, filmy character, and clean spots were found in juxtaposition to rust spots in almost all places. Rough surfaces usually had more rust under the paint than smooth ones, the latter being clean oftener than otherwise. No special difference was noticed between plates and shapes, except so far as the roughness of the surface indicated. On some angles scale was found, and under this scale was oil with clean metal. Machined surfaces were usually clean; there were, however, some rust spots found on these. Horizontal exposed surfaces were no worse than others. The outside of the drum was probably worse than any other part of the bridge; this was no doubt due to the cracking of the surface scale on plates while bending, and to rusting subsequently.

The guard angles were shipped without painting, and after arrival on the work, were thoroughly cleaned and painted; the metal under the paint was clean almost without exception.

The rust under paint was, as usual, found in spots, and from this it is quite evident that it existed before painting.

The surface of metal around rivets was specially examined, but there seemed to be no difference between the surfaces here and those of places remote from rivets, thus indicating that reaming or drilling had no special influence in this matter.

The bridge, having been so recently painted, presented a good appearance externally, no rust spots whatever showing on the paint.

Bellefontaine Bridge.

The Bellefontaine Bridge over the Missouri River near St. Louis was given one coat of iron oxide paint in the shop before shipment

during 1893, and two more coats of the same paint after erection early in 1894.

The external appearance was excellent, no rust spots of any kind having as yet developed.

Under the paint rust was found in most places; and quite an amount in many of them. In this respect this bridge was quite as bad as that at Burlington; it was manufactured at the same shop. Smooth surfaces were probably better than rougher ones, although this distinction was not as well marked as at other bridges. No special difference was noticed between shapes. Lattice bars and tie plates, or, in other words, small pieces, were found cleaner than larger ones. Cover plates were particularly rusty under paint; the fence was also quite bad. Machined surfaces were usually clean, though by no means always; the rust spots which were found were, however, of a very thin character and usually not large. As at Alton no more rust was observed around rivet heads than elsewhere. The tops of stringers and their cross-frames were usually clean, while the tops of floor beams were not. The webs of stringers and floor beams were in pretty good condition, but rust was found occasionally.

Here, again, the guard angles were received on the work without any paint, and had been carefully cleaned before painting; they were clean almost without exception.

Mill and shop marks painted in white lead were frequently visible through the paint and were examined. White paint was always brittle. Under mill marks the metal was always clean, while under shop marks, though generally clean, rust was found occasionally.

The resident engineer reports that not much scraping was done, as the metal looked well when it came with a coat of paint on. Had he suspected the actual condition he would have scraped the whole structure. The same is reported by the resident engineers of the other shop-painted bridges.

The viaduct, while showing rust in spots, as all other bridges have done, was much cleaner on an average than the bridge. This was not manufactured in the same shop as the bridge proper.

Merchants' Bridge.

The Merchants' Bridge over the Mississippi at St. Louis received one coat of iron oxide paint in the shop before shipment in 1890, and two coats of the same paint after erection in 1890.

A great many rust spots were developing in various places, without any very great regularity, over the entire structure, the east main span being probably worse than any others. The rust was usually in small spots; there were some posts, however, as well as some eye-bars, which had very large scales throughout their entire length. These indicated plainly that no care was taken in cleaning the metal originally. The end posts were better than some of the intermediate posts. The floor system was generally in excellent condition except the tops of floor beams in the east span, which were badly scaled. The bridge needed repainting, and when this is done it should be thoroughly scraped.

Under the paint rust was found in many places as usual, but clean metal seemed to predominate. The paint adhered very firmly to the metal where there were no visible rust spots, and was exceedingly tenacious. No difference was observed as to the rust spots under paint on account of location or exposure, and very little on account of shapes of material. Whenever the metal was smooth it was likely to be clean, as had been noticed on all structures. Here, again, no more rust was noticed near rivet heads than elsewhere. Machined surfaces were rusty under paint as well as others. The indications were, however, that this rust was present before painting, as in no case was there a rust spot visible on the exterior of paint on machined surfaces.

Eye-bars were possibly in a little better condition, with some exceptions, than other members.

Many mill marks originally painted with white lead were seen on this bridge and scraped, and the material under them was always clean. The paint used, presumably white lead from its color, was always brittle and came off very easily, leaving the mark plainly cut out in the bright metal against a background of iron-clad paint, which failed to come off on scraping a surface somewhat greater than the mill mark.

It was evident that the badly rusted members had not been cleaned properly in the shops. In one or two cases clay or soil was actually found under the paint, indicating that the metal had been lying on the ground, and in other places it was quite evident that machine oil had not been cleaned off.

St. Louis Elevated Railroad.

The elevated railroad was examined along the levee from the foot of Franklin Avenue until it turns west, and in a few places where it was

accessible west of the levee. This structure was oiled in the shops, and after erection in 1890, was given two coats of patent iron oxide paint of different colors, the first coat looking very much like red lead. The paint was not in specially good condition; rust spots had begun to show in a great many places on the posts and stringer webs. These spots were generally very small, but indicated pitting, inasmuch as they were in the shape of open paint blisters. In some places these blisters were very numerous and hardly a post or girder was free from them. Under the paint the iron was as usual rusty in spots, and no regularity was observed as to exposure or shape of metal. Generally the rust under paint, where it had not worked through, was only in thin films; some places, however, were found which were quite badly rusted. It is said that special pains had been taken to clean this metal after erection, inasmuch as it had been lying on the levee very long and had become very rusty before erection. The paint was not specially tough and came off rather easily; in some places it was even brittle.

Some distance from the levee, but east of Twelfth Street, the viaduct was in process of extension. The new work was oiled in the shops before shipment. Through the oil the character of surface was plainly visible; while it was no doubt as clean as the average of new work, there were, nevertheless, many rust spots on the metal, there being no place 6 ins. square where there was not some kind of a rust spot. This new work was being painted with a mixture of litharge and charcoal ground in oil, made specially for the company after its receipt. This paint is said to have given excellent satisfaction in the tunnel, where it has been in use for five years, and where it has proved superior to any other. Not much attention was being paid to scraping the metal before painting.

Twelfth Street Viaduct, St. Louis.

This viaduct was quite old and was about to be taken down and replaced by a new structure. In passing under it, it was observed to be exceedingly rusty everywhere and some of the posts to such an extent that the metal, where originally in contact, had spread on account of rust developing on both surfaces, and had forced off the heads of the small rivets. These posts were generally covered with scale from $\frac{1}{8}$ to $\frac{1}{4}$ in. thick. One or two of them were scraped somewhat, and a few paint spots were found. The structure had evidently been painted a good

many times with paint of various colors, the one next to the metal being a dark brown, indicating iron oxide. Wherever a paint spot was found remaining, the metal under it was found clean, but unfortunately very few spots of paint were found on the structure. This structure had been standing over 20 years, and the fact that the metal was still clean under a few paint spots indicated plainly that the paint, even though it had been iron oxide, protected the metal, and that had the entire surface been clean when paint was first applied, no doubt it would still be in fair condition.

Union Passenger Station, St. Louis.

In passing along the street on the east side of the Union Passenger Station, and, therefore, in a position where the metal could not be reached for purposes of scraping, but where at the same time it was not exposed to any extent to the smoke of engines, it was noticed that the general appearance was good. One post was discovered, however, which had large scales of rust on it throughout its entire length. H. P. Taussig, M. Am. Soc. C. E., Chief Engineer, informed the author that this structure was painted with red lead in the shops in 1891, and after erection, in 1892, was painted with two coats of red lead mixed with lampblack. Mr. Taussig was not satisfied with red lead, inasmuch as he applied the best he could get to the bases of the columns and afterwards concreted around them, and found that in six months the paint was entirely gone.

Mound Street Viaduct, St. Louis.

This structure was erected in 1890 and received two coats of iron oxide paint. It was beginning to show some rust spots at various places, but these were not bad. Under the paint the usual condition of clean and rusty iron was found, the clean predominating. The paint was very tenacious and adhered firmly to the iron.

St. Louis, Kansas and Northwestern Round House.

The roof girders of the round house, which were erected in 1893, were painted in the shop with a carbon primer paint, and after erection received another coat of the same paint. The paint was still in a soft condition, and was, therefore, easily scraped off. Under the paint, however, the metal was perfectly clean, even directly over the stacks of the engines.

Rush Street Bridge, Chicago.

This is the first highway bridge over the Chicago River from its mouth. It was built in 1884, and was apparently originally painted with an oxide of iron paint. It was repainted in 1892 with a light colored paint, reported by the men in charge as being lead and oil.

The condition of the paint was good, there being very few rust spots visible. The paint itself was brittle wherever scraped, and under it numerous rust spots were found. As usual, the rust was in spots, and perfectly clean metal was found about as often as rust. Some of the rust spots were quite bad, but they had not come through the paint.

State Street Bridge, Chicago.

The State Street Bridge was built in 1887, and was first painted with red lead and subsequently with a light colored paint, presumably white lead tinted. It was repainted in 1892 with paint of the same color as the Rush Street Bridge, which paint was apparently of a poor quality, as some of it had washed off and was badly cracked. The condition of the paint as a whole was good, however, very few rust spots being visible.

On scraping, the paint was found quite brittle, although the red lead seemed to adhere better than the paint on the Rush Street Bridge. Rust spots were again found under the red lead, although the metal usually was clean.

The drum and floor were evidently painted with an iron oxide paint, which was wearing quite as well as the paint on the trusses. On the drum two mill marks were discovered, which were well covered with paint, while the surface immediately adjoining was decidedly rusty. Apparently in the first painting these marks were not covered, and the metal around them left free from paint, which is not an unusual practice. The metal in these unpainted spots evidently rusted before final painting, and the rust had eaten through the paint, inasmuch as the drum in other places was in fairly good condition. These mill marks upon being scraped showed perfectly clean iron under the white lead. Other parts of the drum, where the oxide of iron paint was still in good condition, were equally clean. The floor was badly rusted; it was inaccessible for scraping.

Dearborn Street Bridge, Chicago.

The draw bridge over the river on this street was built in 1872, and served for many years at Wells Street. It was moved to its present site in 1888. It had evidently been painted with some form of oxide of iron paint originally, and had not been repainted frequently, as the paint was very thin, the last coat being probably applied in 1888 and being of the standard kind used by the city at that time, viz., an iron oxide mixed with oil according to the city formula. The external condition, however, was good, and, on scraping the metal under the paint, it was found remarkably clean, very few rust spots indeed being found. The paint was fairly tough and adhered pretty well to the iron.

Dearborn Street Viaduct, Chicago.

The bridge over the Chicago and Northwestern Railroad tracks was built in 1888. It was painted with a patent iron oxide paint and had not been repainted since. There were many rust spots visible on the trusses; the floor was not examined. The paint was tougher than that on the other bridges along the river in this neighborhood, and the metal under it was generally clean, although rust spots were found in places as usual.

Clark Street Bridge, Chicago.

This bridge was erected in 1889. It was painted in the shops with red lead, and after erection with the city's standard iron oxide paint.

The trusses showed considerable rust everywhere, especially on top of upper chords and near the floor where the paint is subject to abrasion. The floor beams, approach girders and the members under the floor in general were in much worse condition, specially the approach girders, where the webs were decidedly rusty. The horizontal surfaces, both on top of the top chord and on the under side of girders, were much worse than vertical surfaces.

This bridge, though built one year later than the bridge on Dearborn Street over the tracks of the Chicago and Northwestern Railroad, was much rustier, and the paint was very much more brittle and did not adhere as well to the iron.

Wells Street Bridge, Chicago.

This bridge was built in 1888, and was painted the same as the Clark Street Bridge.

The trusses were in much the same condition as at Clark Street, though perhaps a little better. There was no class of members free from rust, although some were worse than others, and some classes of surfaces were in worse condition than others. Here, again, horizontal surfaces, as, for instance, the top chord, the top of girders transferring the weight to the drum, the top of the drum, and the under horizontal surfaces of floor beams, stringers and plate girders, were very rusty.

The webs of the girders transferring weight to the drum, the webs of the drum, and the webs of the approach girders, however, showed very few rust spots.

The paint was almost without exception brittle and very easily scraped off.

Where no rust spots were visible, the metal under the paint was comparatively clean, although thin, filmy rust spots were discovered on most of the members that were examined.

It may be stated that in all of the Chicago bridges the floors were practically inaccessible, and were examined only from a distance. They were all in worse condition than the upper work, which is readily explained by the passage of numerous tugs under them producing vast volumes of sulphurous smoke, which, it is well known, is one of the worst enemies of paint.

Lake Street Bridge, Chicago.

This bridge was built in 1886, and is said to have been painted with one coat of red lead in the shop and subsequently with patent oxide of iron paint; there was, however, no indication of red lead anywhere. It had evidently been repainted. The visible condition of the paint was fair, there being many rust spots visible. The paint was quite brittle, and under it were the usual rust spots.

Lake Street Viaduct, Chicago.

This is immediately west of the draw and was built in 1886. It was evidently painted with iron oxide paint. The condition of the paint was good, and on scraping was found fairly tough and generally adhered well; the iron under the paint was clean, as a general thing, although rust was again found in spots as elsewhere. The character of the rust found under the paint was generally the same as heretofore encountered, viz., a bright yellow, which did not seem to be particularly active.

Lake Street Elevated Railroad, Chicago.

Some of the posts on the Lake Street Elevated Railroad were scraped and examined. Although this structure was only one year old, and the paint was perfectly fresh, the iron under the paint showed the usual spots of rust scattered over clean surfaces.

Madison Street Bridge, Chicago.

The draw bridge over the river was built in 1891, and the specifications called for one coat of red lead and oil before leaving the shop. The first coat, however, was not red, but of a greenish gray color. The later coats were to be metallic paint; they were black and thin. The structure showed some rust spots on the trusses and a great deal of rust on the turn-table. The paint was uniformly very brittle, easily removed, and the metal under the paint was generally rusty, although clean spots were found occasionally. The rust, wherever discovered, was very decided, even where it did not show through the paint. The condition of this bridge under the paint, where no rust spots were visible on the exterior, was worse than any of the other bridges on the Chicago River visited up to that time.

The metal for this bridge had been manufactured for some time before it could be erected, owing to delays in building the substructure. During this delay it was stored in the contractor's yard under a shed.

Madison Street Viaduct, Chicago.

The viaduct over the Chicago, Milwaukee and St. Paul Railroad, immediately north of the Union Station, was built in 1891; it was painted next to the iron with a greenish gray paint of the same color as the draw-bridge and with a black paint over this; the bridge had developed a large number of rust spots. The paint was very brittle, and under it the usual rust spots and clean metal were found, rust spots being quite as frequent as clean metal.

Jones & Laughlins' Bolt Shed, Chicago.

In 1884 Jones & Laughlins, corner Lake and Canal Streets, having occasion to put a temporary addition on their building for the storage of bolts, made it a wooden frame covered with corrugated iron. This corrugated iron has now been in place for over 10 years. It was first painted in the mill with a pure oxide of iron mixed with pure

linseed oil, and had been repainted several times since. The exterior showed no pits indicating previous rust, and on scraping the metal was found perfectly clean. On the interior of the building the corrugated iron is exposed and had never been painted since erection; here considerable rust had been developed. The roof was reported as being perfectly tight, and the external conditions as good as the sides.

The method pursued in first painting this corrugated iron is to use a paint composed of pure oxide of iron, made by simply grinding a hematite ore, and pure linseed oil, and applying this immediately after the iron has left the corrugating rolls, it being found that any delay in painting is detrimental to the wearing qualities of any paint. It is believed that the surface of the iron absorbs oxidizing agents immediately after the original scale is broken, which make themselves felt even after paint is put on. It is the experience of the above firm that oxide of iron paint is superior to all others.

Adams Street Bridge, Chicago.

The draw bridge was built in 1889, and the first coat of paint was red lead, with subsequent coats of gray and white, presumably mixtures of lead paints. All the paint was quite brittle and easily scraped off, and under it the metal was fairly clean, but rust spots were discovered on all members.

Adams Street Viaduct, Chicago.

The viaduct over the railroad tracks at the Union Passenger Station was built in 1885. It was originally painted with an oxide of iron paint, and apparently with a carbon paint subsequently. This latter was practically gone, and the original paint was comparatively thin. Under it the iron was unusually clean, although some rust spots were discovered. The paint was brittle in some places and tough in others.

Jackson Street Bridge, Chicago.

The draw was built in 1888; the first coat of paint was apparently red lead, supplemented subsequently by oxide of iron paints. The visible condition of the paint was fairly good, but it was very brittle. Under the paint numerous rust spots were discovered, but most of the iron was clean.

Jackson Street Viaduct, Chicago.

The viaduct over the railroad tracks was built in 1888, and it was apparently painted with an oxide of iron paint. The visible condition of the paint was fair, it adhered fairly well, and was not very brittle, neither could it be said to be tough. The metal under the paint was generally clean.

Metropolitan Elevated Railroad, Chicago.

The rolling bascule bridge over the Chicago River was incomplete at the time of the examination. It had received one coat of so-called red lead, which had very little lead in it, but there was a good coat of oil. Under this paint the usual rust spots were found scattered over the otherwise generally clean surfaces.

The spans crossing the railroad tracks immediately west of the river were erected during the winter, and were first painted with an oxide of iron paint, and subsequently received a coat of zinc and lead mixed. The oxide of iron adhered well to the iron and was fairly tough, although it was not old enough to show what it will do.

Van Buren Street Lift Bridge, Chicago.

This bridge was also erected during the winter, and had just been opened to traffic. It was first painted with red lead, and had subsequently been thoroughly painted with oxide of iron. On scraping this structure, after penetrating the surface, the red lead was found to be exceedingly brittle, and while the metal was usually clean, many rust spots were found.

Harrison Street Bridge, Chicago.

The draw bridge was built in 1877, and had been painted apparently exclusively with iron oxide paints. The posts are of the form known as the American Bridge Company's columns. The shapes entering into this were comparatively rough, and under the paint on these posts the metal was usually rusty. On the bars near the turn-buckles the metal was generally clean, while at some distance from them rust was more common. The external condition was good.

Harrison Street Viaduct, Chicago.

The viaduct over the railroad tracks was built in 1881. It was painted with an oxide of iron paint next to the iron, on top of which

there was a light color, presumably white lead, and the surface was again oxide of iron. The bridge showed some rust spots, but not many. With the exception of the first coat, the paint was quite brittle; the first coat, however, adhered well to the iron. The metal under the paint was comparatively clean, but showed rust in various places.

Wisconsin Central Bridge at Polk Street, Chicago.

This bridge was erected in 1889. Some of the members were evidently painted first with red lead and others with oxide of iron; subsequently the structure was painted black, probably with some carbon paint. The bridge was very rusty in all its parts. The oxide of iron adhered to the metal much better than the red lead and was tougher. Where rust had not already penetrated the paints, the metal under the paint was generally clean.

Polk Street Draw, Chicago.

This structure is a rather primitive affair, consisting of a pair of box girders tapering from the center towards the ends and supported by a system of hog chains. It was built in 1872. The structure had evidently been painted with iron oxide paint only, it being all one color. This paint was in good condition, very few rust spots showing, and under the paint the surface of the metal was very clean.

Polk Street Viaduct, Chicago.

This structure was built in 1887. The first coat of paint was apparently of oxide of iron; subsequently it was painted with a light color, presumably white lead, and on top of this oxide of iron. The external appearance of the paint was good, the upper coats were quite brittle, the first coat adhering well to the iron. In most places the metal under the paint was found to be clean.

Taylor Street Bridge, Chicago.

This structure consists of an approach which runs from Polk Street, parallel to the Wisconsin Central track, to Taylor Street, thence west to the river, and is composed of iron bents and plate girders erected in the fall of 1894, and a draw bridge across the river, built in 1872, originally used at Adams Street, and moved to Taylor Street in 1889.

The old draw was originally painted with a brown paint, evidently a mineral paint, and had not been repainted very often since, as the paint was very thin and practically of the same color throughout. The external appearance was very good, there being very few rust spots. Under the iron some rust spots were found, but as a general thing the metal was very clean. In places where rust spots had developed and broken through the original paint, a subsequent coat had covered them thoroughly. The paint was rather tenacious, and adhered to the iron fairly well.

The first coat of paint on the new viaduct at the east end of the draw-bridge was specified to be red lead, though analysis proved it to be mainly iron oxides; the subsequent coats were of iron oxide. The external appearance of the structure was good, no rust spots being noticed in any place except on the railing. Pains were taken to examine some of the girders immediately over the main tracks, and these were found without any rust spots. The same was true of the girders along the Baltimore and Ohio freight depot, between Polk and Taylor Streets. These girders are continually exposed to smoke from engines passing under them.

On scraping, a few spots were found where the red paint adhered exceedingly well; generally, however, there was little difficulty in getting through the surface, and when once the scraper had reached the bright iron under the red paint, it was an easy matter to scrape the paint off clean, it being very brittle. The paint had not been on long enough to display the mill marks; one of them was, however, accidentally discovered, and this, as usual, scraped off easily. Immediately adjoining this mill mark the red paint adhered better than in any other place, and was, perhaps, the only place where it could be called satisfactory.

Under the paint rust spots were found as usual, clean metal predominating.

Taylor Street Viaduct, Chicago.

This viaduct carries Taylor Street over the Pennsylvania and Chicago, Burlington and Quincy Railroads. It was oiled in the shop, and after erection in 1891 was painted with the city's standard oxide of iron paint. The paint was very thin and brittle, and the structure was very badly rusted. Wherever no rust spots showed through the paint, the metal was usually clean under it.

The posts supporting the main span of this viaduct were painted with P and B paint. This paint was very thin, did not adhere well to the iron, was not cohesive in itself, and when scraped it came off very readily in the shape of powder. The metal under this paint was generally clean, but it would evidently stand no abrasion whatever, the paint rubbing off with very little effort.

On the girders constituting the approach to this bridge the paint was scaling off, and a large portion was already gone. The exposed metal was very rusty in most places. There were many places, however, where the iron was still very bright, showing that the oil originally put on was still protecting it. These bright spots had undoubtedly been exposed for less time than the others. Wherever the paint was still intact, it could be scraped off very readily, exposing bright, clean metal.

Lassig Bridge and Iron Works.

A visit was made to the shops of the above company to observe the condition of metal after manufacture into structural work and before painting. This company houses all metal immediately on its receipt, and it does not leave cover until after it is painted, except possibly in summer, when the weather is suitable.

A number of plate girders were finished and being given a coat of linseed oil. Notwithstanding that the metal had been housed, there were many rust spots on the web plates, and also some on the angles. The latter were covered with scale. The metal was being cleaned by means of putty knives and whisk brooms before oiling. Steel brushes were also used. If there is anything unusual in this method of cleaning at shops, it is perhaps on the side of thoroughness. After cleaning, the plates still showed thin, yellow rust spots, and these showed plainly, but of a darker color, after the oil was applied.

The oil was scraped from some rust spots under oil on dry girders which were in the yard, and the yellow color so often found was developed.

Members of a bridge built by this firm some six years ago, which bridge had met with an accident, were in the shop for repairs. These had been first painted with the patent iron oxide paint noticed on the Sioux City Bridge and repainted in 1893. Practically no rust spots were to be seen, and it was very difficult to scrape off the paint on account of its toughness and adhesive qualities.

Some metal was examined which had been lying in the storage room for a year. This was entirely covered with rust, even though exposed to neither sun nor rain.

The following bridges mentioned in the foregoing pages, viz., Cairo, Memphis, Merchants' at St. Louis, Bellefontaine, Leavenworth, Rulo, Nebraska City, Plattsmouth, Union Pacific Railway Bridge at Omaha, Blair Crossing, Sioux City, Alton, Burlington and both of those at Minneapolis, were painted with a pure iron oxide known in the trade as Cleveland iron-clad paint, brown purple, No. 3. It was generally bought dry, and mixed with pure boiled linseed oil on the work. The chemical composition of the pigment, according to an analysis reported by the manufacturers, and to an independent analysis made by R. W. Hunt & Company for the author, is as follows:

	Manufacturer's Analysis. Per cent.	R. W. Hunt & Co.'s Analysis. Per cent.
Sesquioxide of iron	93.68	92.40
Silica	3.20	3.36
Alumina	3.06	1.69
Lime	....	0.84
Organic and volatile	....	0.85
Magnesia	....	0.48
Sulphur	Trace.	0.029
Loss	0.06	0.351
	100.00	100.00

It is a selected natural iron ore simply ground fine.

The painting itself was done by men employed by the day under the direction of the resident engineer. For this work painters were avoided, as it was found that intelligent laboring men were more to be relied on for thoroughly scraping and covering the metal.

The patent paint mentioned was all from one manufacturer, although it might be of different brands. It was, however, an iron oxide paint, the pigment in one brand being composed of about 33% of iron oxide and 60% of silica, calcium sulphate and calcium carbonate mixed, as determined by three analyses from the same number. These analyses varied widely, however, in the relative proportions of the latter ingredients, and the wearing qualities of the paint as observed by one large consumer were by no means uniform, paints furnished at first being better than those furnished more recently, and a paint from a

different manufacturer containing more oxide of iron has now been substituted by this consumer.

The city of Chicago has painted its bridges for a number of years with a paint specially prepared after its own formula, the pigment being an iron oxide of substantially the same analysis as that first given above. Pure boiled oil is specified.

From the foregoing observations it will be noted that rust was found to a greater or less extent on all structures examined, regardless of location of structure, of member in structure, or of surface of member. It will be further noted that this rust occurred practically always in spots, or, in other words, that clean metal could readily be found adjoining a rust spot, if the scraping was carried far enough. In most of the structures examined the larger part of the metal under the paint was found clean.

The character of the rust spots thus found under the paint seemed to be wholly independent of the time the structure had been in service. Most of it was simply the thin yellow film easily brushed off and evidently doing no harm, as it was found no worse in bridges 12 and 23 years old than in those one year old. In some cases deeper rust was found, but this was at least as frequent in the newer bridges as in older ones, and, in fact, it is believed rather more frequent. The Blair Crossing Bridge, built in 1883, was much cleaner under the paint than the Bellefontaine Bridge, built in 1893, and the Dearborn Street draw is much cleaner than that at Madison Street.

It would seem from the above that it was not unreasonable to conclude that pure iron oxide used as a pigment in paint is not a cause of rust on metallic structures exposed to air. This question was the chief occasion for making the investigation, and, to the mind of the author at least, the question is satisfactorily settled, notwithstanding the theory advanced by many to the contrary. Furthermore, wherever paint had been applied to clean metal, the metal had evidently been protected so long as the paint lasted, no matter what the paint was, as was shown on some of the Chicago bridges, notably the Taylor Street Viaduct.

As for the lasting qualities of different paints it is to be regretted that the variety examined was not greater, that the exact composition of those found was often unknown, and that the red lead had in no instance been in service over seven years.

It has been justly said that a paint as a preserver should have good covering power, should be neutral to the metal to which it is applied, tough, should adhere well to the metal, and be durable.

As the paints examined consisted almost wholly of iron oxides and leads, these alone will be discussed at length.

The covering power of iron oxide has not been questioned so far as the author knows. On the other hand it is generally admitted that red lead, which has recently been preferred, spreads very poorly and that it is, therefore, difficult to get it applied properly. Red lead is said to combine chemically with oil, and to form a soap which sets in a comparatively short time. The mixture or compound must be applied before the setting takes place, or it is of little value. The theory of chemical combination is quite commonly accepted and is supposed to be the valuable feature of this class of paints. Some authorities in the matter say, however, that there is little chemical affinity and object to any such affinity, preferring a pure mixture with linseed oil to any chemical combination.

Linseed oil, so far as known, is the best liquid within reasonable cost that can be used for paints, and is, in fact, the preserving agent of the paint. It is, however, readily destroyed by weather, and to preserve it a pigment is mixed with it. The more inert this pigment is to the oil, and the more stable in itself, the better. Iron oxide is inert with oil, and, so far as made from natural ores, it is one of the most stable pigments known.

The worst enemy of paint is water, and this attacks the oil. The porosity attributed to oxide of iron paints by many is the porosity of the oil, and not of the mixture or pigment. Experiments were made by C. B. Dudley, M. Am. Soc. C. E., to illustrate this. He found that while linseed oil alone, after being dried, absorbed water rapidly, this absorption decreased the greater the amount of iron oxide present, and practically ceased finally.

Paints forming chemical combinations are more liable to deterioration, the oil having already been attacked.

Many of the paint soaps formed by a combination of pigment and oil, while insoluble in water, are nevertheless not durable.

The neutrality of paint to the metal has already been mentioned so far as pure iron oxide is concerned. Oxides made from copperas or other sulphur processes are not considered here. Lead paints are un-

doubtedly neutral, as is shown by the numerous white lead mill marks which were scraped, and under all of which the metal was perfectly clean.

As for toughness and adhesive qualities, iron oxide has again been said to be brittle and easily removed, while lead paints are claimed to be the opposite. The investigation has pointed to exactly the opposite conclusion. Where pure oxide of iron with pure oil was used, the paint without exception was tough, and, where dry, adhered firmly to the metal, it being practically impossible to scrape it off. In the case of the Plattsmouth Bridge, where some of the paint came off easily, it was in tough leathery strips, and this was due to imperfect drying quite as much as to anything else.

On the other hand, but a single case was found where lead paint adhered well or was tough. In this one case the red lead did both. The numerous mill and shop marks examined were without exception more brittle than the oxide of iron paint around them. It has been questioned whether the red lead and white lead examined as such were really what they looked like. No chemical analysis was made and the authority for its genuineness is only the specifications, the integrity of the contractors, and the color of the pigment. If, however, it is impossible to buy an honest article of a specified kind, the endeavor to get it had better be abandoned for something one can be sure of, and which is better than the inferior article purchased under a high-sounding and high-priced name.

It is possible, and in fact probable, that much of the observed brittleness was due to adulteration of the oil by means of turpentine or benzine, or other petroleum products. The latter are known to be positively injurious to paint, causing scaling or want of adhesion, while the former is at best only inactive except as a diluting agent, and dilution is in itself objectionable. Lead paints being more difficult to spread than the iron oxide, the tendency to use diluting agents with them is much increased. A case may be cited where a painter was engaged to apply pure red lead and oil, and abandoned the work because the paint was too difficult to spread and the use of turpentine was not allowed.

As for durability, the case of the Blair Bridge may be cited as one illustrating that of pure oxide of iron mixed with pure oil. This bridge has now stood nearly 11 years since the second and last coat

of paint was applied, and it is in very fair condition to-day, in fact much better than some of the newer ones. Furthermore, where rust has not actually eaten through the paint, the latter is good for some years yet. A still older bridge, that at Bismarck, N. D., might be cited, this having been erected in 1882, painted in 1883 with the same oxide as the Blair Bridge, and not since, and it is reported in good condition still. This bridge was not, however, visited in connection with this examination.

The durability of paint is evidently largely dependent on climate. The Bismarck Bridge is in a high latitude, and the paint has lasted many years. The Memphis Bridge is pretty well south, and rust has developed much more rapidly.

There is no structure in the list examined that has been painted with red lead which can be compared with the Blair Bridge, either for age or general conditions. The Winona Bridge is only about four years old, and while at present its appearance is better than that at Blair, the condition of the paint is much worse and there are many scales and blisters which will soon come through. In this connection it may be noted that it is claimed that red lead will not blister, the contrary of which, however, is decidedly in evidence at Winona. As the paint here was bought dry and mixed with oil as used, the conditions should be reasonably favorable to red lead. It is believed, however, that blistering is quite independent of the paint.

Comparing the Dearborn Street Viaduct with the Clark Street Bridge in Chicago, the evidence is somewhat in favor of the former. Comparing the old Dearborn Street draw and Taylor Street draw with the Clark Street and Wells Street Bridges, the first two show to decidedly better advantage. In both the above comparisons the iron oxide comes out ahead. This may, perhaps, be accounted for from the fact that these Chicago bridges are constantly exposed to the sulphurous fumes from coal smoke. White lead is more rapidly decomposed by sulphurous acids than any other paint, and red lead is not far behind, while iron oxides are affected very little.

In old New England barns painted with Venetian red and white trimmings, the white lead wears off the trimmings entirely long before the red iron is much affected.

Furthermore, the lead compounds are always artificial combinations, while iron oxides can be obtained in abundance from Nature without any preparation except grinding.

The trainshed of the St. Louis Union Station painted with red lead throughout is already scaling.

Only two cases of carbon paints were observed, and these were not old enough to show their qualities. Neither, however, were tough nor adhered specially well to the metal, though both protected the metal.

It is hoped that something interesting may be brought out in regard to these paints in the discussion.

The lasting qualities of paints colored with lampblack are well known. Old signs, where the white lead ground color has been gone for years, still have perfect letters in black.

Many asphalt paints have been on the market, but some of them contain absolutely neither asphalt nor other carbons; and others, instead of being true asphalts, are coal tar mixtures. It is claimed for true asphalts that, unlike petroleum compounds, their oils are non-volatile, and that once properly applied, they last practically forever.

But after all that has been said about paints for preserving metallic structures, it is necessary to look first to the condition of the metal to be preserved.

It will be clear from the observations given in detail in the first part of this paper that the rust which exists under the paint is not a thing which has developed on account of imperfect covering qualities of the paint, but has been there from the day the paint was first put on. In the majority of cases this rust is doing no harm under good paint, and the owners of a bridge need not feel that they must remove all old paint, because the structure is rusty in spots under it. In repainting a structure it should be thoroughly scraped and brushed with steel brushes; but where old paint adheres thoroughly to metal, it is a good foundation to build on, and it should be the aim to get the rust spots equally well covered.

Too little attention has been paid to cleaning the metal before the first coat of paint has been put on, and usually the metal has been painted as quickly as possible to cover up the spots.

It is well known that plates are rolled with smoother surfaces or with less scale than shapes. After rolling, the material lies out of doors for a time, both at the mill and bridge shops, for various reasons, before being manufactured into structures. Plates lying on top of each other form a covering for themselves, while shapes are not so well

adapted to this. Moreover, plates, being smoother than shapes, are less susceptible to the influences of weather. While thus exposed, no doubt the formation of most of the rust is begun, and there is nothing to prevent its development until the material is assembled into a member and finished. It is then generally pushed out of doors and painted.

It should be cleaned and scraped, but from the author's observation this is done superficially, if at all, and in some shops only when the inspector is at hand to see it done. Many inspectors are not aware of the importance of proper cleaning, and are satisfied when metal is entirely covered.

It is one of the most difficult things for an inspector to obtain good cleaning of metal at a shop, even if the management is inclined to have it properly done. He can rarely devote much time to the painting, and, as a result, the men intrusted with that work get the rust out of sight with the least possible effort by simply covering it up with paint. If the rust so covered up has not begun to pit the iron, the chances are it will never do any harm; but if it is already well developed and of some thickness, it will have enough oxidizing agents in its pores to develop more oxide, swell up, crack the paint, and the continuation is obvious. In such a case the paint is usually condemned as unsatisfactory, when it is probably not at fault at all.

The first requisite, therefore, in the direction of preserving iron structures is to insist on absolute cleanness of metal before any paint is applied.

Probably the best way of securing such a condition would be to clean the metal from scale immediately on leaving the rolls and coat it then. The uniformly clean metal under mill marks points strongly to such a proceeding. If linseed oil were used for this purpose, the pieces could easily be immersed whole at a very small cost.

This would undoubtedly add a little to the first cost of the metal, but such additional cost would be saved in the final painting, if not sooner. Undoubtedly some of the preservative coating would be burned off in riveting, but this would be little, and these spots, together with the new rivets, could be covered immediately after riveting. Forged members which are annealed could be coated to best advantage after annealing.

If this plan is impractical, the cleaning could best be done in the

shop after manufacture, either by rotary steel brushes operated by power, by the sand blast, or by pickling. The portable drill might be developed for the first process. If metal were treated in some such way as above indicated and cleaned perfectly, the question of a proper and durable paint would lose much of its importance. There ought to be no reason why such results should not be accomplished.

The manufacturer would, of course, expect to be paid for the extra work, but the result would well justify the cost.

Under present conditions it is necessary to get the best cleaning in the shops that can be exacted. It is the opinion of the author that the best thing to apply there is a coat of pure linseed oil. Boiled oil has been preferred in the past, because it dries more rapidly than raw oil, but if a little time can be given the latter to dry, it is, no doubt, better, as it will penetrate more readily the minute surface cracks and any little remaining rust, and is less likely to be adulterated than boiled oil.

With a coat of oil nothing is invisibly covered up, and if scraping and cleaning are not properly done, it will be apparent,

After erecting metal so treated, the engineer in charge can readily see how much scraping is necessary and can have it done before paint is applied. When paint has been applied in the shop it usually looks well when erected and gets no scraping; additional coats are put on. The whole does not always wear well, and when it does not, the paint is called poor.

Some criticism has been made against using oil as a first coat, the objection being that pigment cannot get next to the metal. As long, however, as the oil is the principal preservative ingredient in paint, this objection does not seem a good one. Paint certainly adheres as well when applied over oil as when applied directly to metal, and lasts as long. The Blair Bridge may be again cited as an illustration.

That metal is likely to be cleaner if oiled in the shop than if painted may be illustrated by the Leavenworth, Nebraska City, Omaha, Blair, Sioux City and Cairo Bridges, as against the Alton, Bellefontaine, Burlington and Merchants' Bridges. The former had quite clean metal under the paint, the latter very rusty metal; the adhesion was good in all.

Care should be taken to have surfaces to be painted free from dampness, and that new paint does not freeze. Many an otherwise good

job of painting has been spoiled by applying paint in rainy or freezing weather.

If metal has been properly cleaned and paint properly applied, there need be no fear that any paint, composed of pure oil with a good pigment, will not protect the metal so long as the paint lasts.

The selection of a paint becomes a question of durability under conditions which at present scarcely exist.

The present investigation fails to point to red lead as the one pigment above all others for painting iron structures exposed to air, but rather that it should be avoided.

Iron oxide is far preferable, as the author sees the matter, aside from the question of cost, and in cost the advantage is certainly with it.

DISCUSSION.

C. B. DUDLEY, M. Am. Soc. C. E.—From the standpoint of the chemist, the speaker was unable to say, after 8 or 10 years of careful study, that he knew of anything that can be applied to an iron structure which will absolutely prevent corrosion. No one apparently knows, beyond question, what makes iron corrode when exposed without covering; there are a number of theories, and a good many experiments have been made. If three things are kept away from iron it will never corrode. These three things are moisture, oxygen and carbonic acid, but it is problematical if any one of the three being absent, corrosion or rusting would not take place, although it is pretty positively known that water alone, without free oxygen and without carbonic acid, will not corrode bright surfaces for months. It is said that if moisture and gases can be kept away from the surfaces, they will not corrode. The inference is that paint will keep those things out, but unfortunately it does not, and that is the key to the situation. He knew of no paint which will exclude, after it is dry, moisture and gases from the surface coated with it. Linseed oil alone, spread on a surface and dry, is about like a sponge. Take a piece of glass, coat it with oil and allow it to dry a month; then look at the piece of glass under a microscope, and pretty satisfactory proof will be seen. If a microscope is not available, put a drop of water on the surface and cover it up so that it will not evaporate. Dry linseed oil, such as has been subjected to a moderately dry atmosphere for a month, when treated with a drop of water on the surface will look on the next morning much like a shriveled apple. It will lift up from the surface and will dry down again

Mr. Dudley.

Mr. Dudley. if the water evaporates. Linseed oil alone is not a substance which keeps out moisture and gases, but when mixed with pigment it keeps them out better. Take one glass and coat it with linseed oil; on the next glass put 5% of pigment of any sort that does not have a chemical action with the oil; on the next one put 10 parts of pigment and 90 parts of oil, and so on until the mixture is too thick to spread. It will be found that with an increase of the pigment the action is less with the drop of water. The pigment apparently fills the pores which are produced when the linseed oil dries, in a measure, and helps to keep out the gases and moisture. Linseed oil, when it dries, is no longer an oil, and it has undergone a chemical change; chemists call it linoxyn. It is fairly demonstrable that two or three things have taken place during the drying; first, there has been an absorption of oxygen; second, there is very little doubt but there is an elimination from the oil during the process of drying, of carbonic acid and perhaps water vapor. Those two substances passing out of this thin layer of liquid leave little apertures; they must have apertures to come out. If pigment is mixed with the oil apparently the apertures are less large, or are partly filled up. The best paint to prevent corrosion is a mixture of linseed oil and lampblack, but this paint dries too slowly. To overcome the difficulty of exceedingly slow drying, the lampblack may be mixed with any inert substance, yellow ochre, oxide of iron or possibly red lead (although the last may cause a chemical change in the oil) retaining as much lampblack as is possible and still get satisfactory drying.

Mr. Emery. CHARLES E. EMERY, M. Am. Soc. C. E.—Iron ships are peculiarly liable to corrosion, being subject to alternate states of moisture and dryness under the influence of salt water and salt air, all independent of galvanic action, which cannot be entirely prevented. The methods adopted for preserving iron ships have, to a large extent, become well settled. They consist of untiring vigilance and the free use of good paint. New paints, so-called preservatives, anti-rusting and anti-fouling compositions have been tried, but red lead is most depended upon. He had been instructed by one of the Government departments some 10 or 12 years ago to make an examination of one of the earliest iron vessels constructed in this country, being informed preliminarily that there was very little money with which to make repairs. The vessel was built before 1861 and before angle irons were in vogue. The frames were of bar iron bent edgewise and the plates fastened on by clamps extending over the bars and riveted down each side. The vessel was very lightly constructed originally and of light draught for use in shallow waters; after the civil war it had been fitted as a revenue cutter and at the time of the examination was laid up at Mobile, Ala. The officers had reported that masses of rust 2 ins. or more thick had been removed from the plating inside the hull, and considered the

vessel must be in a dangerous condition. It appeared on examination that there were masses of what appeared to be rust ½ in. to 2 ins. thick, which in many cases had to be broken off with chisels, bars and hammers and would finally show a rusted surface on the interior plates of the vessel. Some of this scale adhered so persistently that the impression was created that the chisel must go through the bottom of the vessel, but sound iron was in all cases found underneath it. The phenomenon was due to the way the vessel was cared for. The men were supposed to scrape the iron clean and paint it periodically. Some interior parts were inaccessible, others difficult of access, and there was some neglect in the scraping so that the paint at some points frequently went on over previous collections of rust. Moreover in some parts of the ship, cleanliness was promoted by whitewashing, which was entirely removed by the scraping, so that the mass taken off was a conglomerate, colored throughout with rust, but representing very little weight of iron. At many points, particularly near the frames, no corrosion had apparently taken place, and the scraping showed paint to all appearance like that applied originally. The greatest corrosion appeared to occur where the original coating had been in some way broken. Mr. Emery.

The speaker had the vessel put on a dry dock and the bottom hammered from stem to stern. The plating was originally very light, and where no corrosion had taken place it did not appear to be more than $\frac{5}{16}$ in. thick, and in the 25 or more years of service this had become reduced at points to a mere shell through which it would have been easy to drive a hammer. It was found, however, that there was much metal left of nearly the full thickness, the thin spots were generally not of large area, and by cutting holes it was found that many of them still contained ½ in. of good metal. The bottom was so much of a springboard that it was difficult to cut a hole with a chisel from below and he persuaded a number of the officers and men to try it, with the result that all had very much respect for the old vessel when the examination was completed. On account of his instructions he decided simply to patch over those places on the hull which sounded light and in which any part of the area was less than $\frac{1}{16}$ in. thick. Although a considerable number of patches were required, still the surface covered was a very small proportion of the whole bottom. The officers ran the vessel several years more without further repairs, when she was ordered North, all her woodwork was stripped off, the iron hull thoroughly cleaned, the thinnest points broken through, and the vessel rebuilt as a composite vessel by placing on it an outer skin of yellow pine plank bolted in most places to the old plating and occasionally through washers hooked over the frames, the heads being let into the wood and cogged with wooden plugs dipped in white lead. It was only found necessary to remove about a dozen of the old frames in making this

Mr. Emery. reconstruction, though here and there where the frames had become thin angle iron was placed against them. The vessel is still running.

He drew the conclusion that it was impossible for an iron structure to be wholly destroyed by corrosion when any attempt had been made to care for the same. He supposed that the rust was principally due to the carbonic acid in the atmosphere, which is absorbed by any moisture present and finally an active corrosive solution is formed. A surplus of water would dilute the solution and check the action, and the drying of the plates would also check it, but the recurrence of moisture would cause a repetition of the phenomena and further corrosion. It appears, therefore, that the covering up even of rust had some beneficial effect, as it prevented further action, though parts that were actually well cleaned and then thoroughly covered were better protected. The masses of rust which collect on bridges do not represent any large quantity of iron removed. The oxide is of very much greater bulk than the iron itself and may be removed by thorough scraping, and the surface covered so as to stop further injury. He thought, however, that the experience with the old ship showed that even if some little rust is left it may be so thoroughly covered up as to do no further injury. He considered that circulation of air had considerable to do with the rapidity of the corrosion. In the smaller enclosed places of the old vessel the destructive action was not so great as in the central and more open spaces, although the latter were more accessible and received better attention. A cement covering doubtless acts on this principle so long as it is kept either dry or wet, but not alternately dry and wet.

Attention was called to a paper by the speaker in which it was shown that the return pipes of an underground steam system corrode very rapidly while the steam pipes remain intact, the apparent reason being that the carbonic acid which is absorbed by the soil acts most virulently at or a little above the temperature of steam at atmospheric pressure.*

Mr. Morison. GEORGE S. MORISON, President Am. Soc. C. E.—There is one feature of this paper which seems to have been left out in this discussion, much as it deserves attention. A great deal has been said of the use of different pigments and of their durability, but the question of how the iron is to be put into proper condition to receive the pigment is the most important thing of all. The author suggests that it be cleaned with steel brushes, by the sand blast, or possibly by pickling. William Metcalf, Past President Am. Soc. C. E., considers that it is a hazardous thing to pickle iron and steel, that there is danger that the effect of the pickling will never be removed. It is absolutely necessary, in order to secure permanent effects from a pigment, that the

*See paper on "District Steam Systems," in the *Transactions* of the American Society of Civil Engineers, Vol. xxiv, p. 192.

paint should come directly on the bright surface of the metallic iron. It is a common thing to note the durability of mill marks, which are usually put on with a poor quality of white lead; the reason of that durability is that they are put on very soon after the metal has left the rolls. It may be necessary to paint the metal for important structures before it goes out from under the roof of the rolling mill. This is the principal requirement; the painting of the metal must not be deferred until it has begun to deteriorate, and that is the question iron manufacturers should take in hand and discuss; the best method of accomplishing this result, the best method of getting the pigment on the metal with least expense, at the earliest possible moment. Mr. Morison.

GEORGE A. JUST, M. Am. Soc. C. E.—The subject is one which does not permit correct conclusions to be drawn from the observations or experience of any one person, both because of the difficulty of ascertaining the exact facts and conditions of each case examined, and the extreme length of time needed to develop the absolute value of any particular method. Even the paper seemed to the speaker to show this, and it is only by the collation of the experiences of the many that it will be possible to decide upon a method which will prove an advance on present practice. For this reason, the paper has a distinct value in adding data to the present meager knowledge on the subject. A proper solution of the question would be a marked step in advance, for not only must metal structures exposed to the weather receive attention, but also those skeleton frames which have in late years played such an important part in the rebuilding of the larger cities, and are ordinarily assumed to be fully protected by their encasing material. In many cases, however, the protection afforded is but slight, since one of the objects of building in this manner is to secure the use of walls of less than usual thickness. In many cases the columns and girders of these frames are surrounded by no more than 4 ins. of brickwork, an entirely insufficient protection against the weather. This condition of affairs has helped to raise the question of the life of such structures, of the relative rate of corrosion in cast-iron, wrought iron and steel, and of methods of protection which should prove effective. For a solution the investor has turned first to his architect, and then to the engineer, who, however, has also been unable to shed much light on the subject. Mr. Just.

At present no better practicable method of protection is known than a good paint well applied. The engineer has, then, to decide what is good painting and what constitutes a good paint. Patent paints and compounds which may have had but a limited use cannot come in for consideration, nor can such processes as the Bower-Barff, the use of which has become confined almost entirely to interior iron-work, in which cases, even, it has not proved an absolute rust protector, since the coating will scale, especially if applied to the finer grain of wrought iron as compared with cast-iron.

Mr Just. To secure painting of good quality, as the author has pointed out, a clean and rustless surface is first required. This applies equally well to subsequent coats, as to primers. The vehicle used should be the best, which is generally agreed to be pure linseed oil. The pigment should be neutral, producing no chemical or galvanic action, and as finally divided a substance as is obtainable, in order to mix well with the oil and to fill as completely as possible the pores of the oil formed in drying. The conditions of the weather at the time of application and the care of the laborer will also affect the final result.

Those who have observed the deterioration of painted surfaces of metallic structures will have noted that a rustless surface is a first requisite. The rust spot will swell and burst, either from the self-contained moisture, or from that reaching it through the paint skin. An inspection of the various lines of elevated railroads extending through New York shows this very clearly. Take the supporting columns at any cross street, such as Forty-second, and it will be found that the Second Avenue line with Phœnix columns is generally in a good condition. The paint blisters raised by rust are small and few, and rust is generally found along the edges formed by riveting the flanges of the sections together. The Third Avenue line, having channel-latticed columns, the webs of the channels running north and south, is generally in a fair condition. The iron is still well covered inside and out, but the paint blisters are larger and more plentiful. Other rust is found principally for a distance equal to the height of trucks from the ground, where the traffic scratches and destroys the paint skin. The Sixth Avenue line with closed sections of channels and plates, the plates running north and south, is in a bad condition. Many large broken blisters are found, especially on the webs, and the paint and rust scale are readily removed in large flakes. The cover plates are in comparatively better condition than the webs of the channels, but rust is found along the riveted edges and around the rivet heads, as in the Second Avenue line. The Ninth Avenue line with channel-latticed columns on the down track is fair or rather better than on Third Avenue, while on the up track the open columns built of four 6-in. extra heavy I-beams are in a worse, but hardly bad, condition. This up track is the oldest existing line. The paint blisters on the columns of this line are few and small, and large pieces are not readily found or removed. As on other lines, rust appears in streaks to the height of covered trucks. These lines afford, perhaps, as good an opportunity as can be found anywhere for testing the merits of painting on metallic structures, both because of their unfavorable surroundings, and because of their age; the Third Avenue line, for instance, was built in 1878.

The chief engineer of the Manhattan Railway Company, Mr. J. Waterhouse, stated that the last coat was applied to these roads, from

Forty-second Street northward, in the case of the Sixth Avenue line, in June, 1889; on the Ninth Avenue line in October, 1889; on the Second Avenue line in October, 1890, and on Third Avenue line in May, 1893. From this it appears that the condition of the roads is not altogether indicative of the age of the paint, excepting only that the one in the worst condition is the one that had not been repainted for the longest period. The character of earlier coatings, the location of the various roads and the shapes or sections which form the columns, have probably all affected the result. Mr. Just.

The paint used in each of these cases was mixed according to the company's standard formulas, viz.:

FORMULAS FOR MIXING 50 GALLS. OF OLIVE-DRAB STRUCTURE PAINT, MANHATTAN STANDARD.

	Summer formula.	Winter formula.
White lead, "Jewett's"	300 lbs.	275 lbs.
Bergenport zinc, strictly best quality	175 "	150 "
French ochre, " " "	100 "	90 "
Prussian blue, " " "	1 lb.	1 lb.
(The above pigments to be ground in Campbell & Thayer's raw linseed oil, and the weights given include that of the oil.)		
Lampblack, strictly best quality	½ "	½ "
Boiled linseed oil, Campbell & Thayer	8 galls.	9 galls.
Raw " " " "	15 "	15 "
Spirits turpentine, strictly best quality	3 "	3 "
Liquid drier	2 "	3 "

Mr. Waterhouse further stated that they preferred a lead paint, and that their manner of testing the many mixtures offered the company is to simply paint thin metal sheets with the same, and to expose them under one of their overhead bridges, by the side of sheets painted with their own standard. So far they have found nothing to give them better results than the mixture they have adopted. They like a light colored paint also because the rust streaks assist them in locating loose rivets.

While, as the author points out, it is generally accepted that the quality and life of a priming coat is dependent to a very great extent upon the care exercised in removing mill scale, rust and grease, it is equally well agreed that with present shop methods, even when demanded by the specifications, this is done but superficially if at all. And this will always be so, until the method specified requires such shops, labor and tools, as to form in each case an appreciable element of cost which the manufacturers must recognize as clearly as punching or other labor, and hence include when making their prices for work.

Better results would be achieved in this direction if engineers in charge of important new work were to specify that the material shall go directly from the rolls to an adjoining closed shop or cleaning shed, where the scale is to be removed by light portable power-driven wire

Mr. Just. brushes or other suitable means, and the pieces are at once to be immersed in a bath of pure linseed oil. Then they are to be sent to riveting or other shops when dry enough to handle, and when the work is complete, they are to be sent to an enclosed paint shop, where a good coat of paint of a kind approved or specified by the engineer is to be given before shipment, ample time being allowed for drying. This process could not be objected to on the ground of the economy of the present method, but would be attacked because of the loss of time in getting material into the field, but it is perhaps the only means by which an improvement can be achieved.

Present practice is pretty well confined to the use of iron, lead and graphite or similar carbon paints; which one of these will give the best results can be determined only from wide experience. As to cost and capacity, these paints can be rated about as follows:

	Cost per gallon.	Covering capacity of 1 gall. Square feet.	Cost of paint per 100 sq. ft.
Oxide of iron (Prince's)	$0 53	600 to 700	9 to 7½ cts.
Red lead (National Lead Company)	1 25	500 to 700	25 to 18 "
Superior graphite (Detroit Graphite Manufacturing Company	1 10	600 to 800	18 to 14 "

The graphite paints have had no very extended use for bridges or skeleton frames of buildings, but the rivalry between iron and lead paints is of long standing. It is conceded that the latter sets rather too quickly, and runs too readily when applied to vertical surfaces. It is poisonous, and, as the iron paint makers claim, destroys the oil and forms a coat of iron oxide beneath the skin. The lead paint makers, on the other hand, claim that iron paint is in itself a rust producer, and that it scales and blisters more readily than red lead. The lead paint, however, seems to be growing more into favor with engineers.

It is well to bear in mind what part of the cost the dry pigment or the oil bears to the total cost of painting. In the case of iron oxide the cost of pigment forms about two-tenths, and the vehicle (linseed oil) eight-tenths of the cost of the paint. In the case of red lead paint the cost of the pigment bears about three-quarters and the vehicle one-quarter of the cost of the paint. The mixed paint forms but one-third to one-half the entire cost of painting. The labor, in ordinary bridge painting, without scraping, had been placed at twice the cost of the paint.

In the figures given, the cost per gallon was derived by taking in the case of Prince's "Mineral," 6¼ lbs. of mineral at 1¼ cents, and 6¼ lbs. of raw linseed oil at 52 cents per gallon (7½ lbs. to the gallon), and in the case of red lead, 18 lbs., at 5 cents, and 5 lbs. of oil at 52 cents per gallon. The graphite paint is sold ready mixed, per gallon, at the price given.

CORRESPONDENCE.

CARL GAYLER, M. Am. Soc. C. E.—The paper will increase the attention paid to existing structures, and its suggestions in regard to scraping and painting at the mills and shops will probably have a lasting influence on future practice. The writer wishes to add to these suggestions that the repainting of bridges should always be done by day labor, never by contract. Work like this, where every square foot of surface has to be treated with equal care, can only be done satisfactorily by men who have no interest in slighting it, viz., by men employed by the day and working under the directions of the engineer or a competent foreman, preferably, of course, by the regularly employed repair force of the company or municipality, as the case may be. Every engineer who has had painting done knows how difficult it is to make a painter do proper cleaning and scraping before covering the surface with the paint. Mr. Gayler.

The remarks in regard to the Twelfth Street Viaduct in St. Louis are not correct. The posts have not failed "on account of rust developing on both surfaces of the metal, where originally in contact, and forcing off the heads of the small rivets," but because they were (for the last of them are now replaced) 6-in. octagon Keystone columns with only ¼-in. thickness of metal, and ½-in. rivets spaced 12 ins. apart. Under the greatly increased traffic, since the viaduct was built, the joints in the columns opened and rust formed between the flanges in consequence. The viaduct was furthermore not condemned on account of the condition of the iron work, but a new one was deemed desirable with a wider roadway and easier grades. The principal objection to the present structure, however, was the danger from derailments, as not less than four different times during the last ten years have columns been knocked out from under it.

SAMUEL G. ARTINGSTALL, M. Am. Soc. C. E.—The requirements for paint on bridges and viaducts in a large city are, no doubt, more severe than for those in almost any other location. The usual condition of the atmosphere in a large city is such as to be extremely detrimental to paint on outside iron work. Moreover, the conditions under which the work must be painted are not often conducive to good results. It is difficult to keep the work clean while the painting is in progress, and the painting must often be done in unfavorable weather, or occasion much delay in the work. Mr. Artingstall.

Draw bridges are usually placed at an elevation sufficient to give headroom for the passage of tugs and other low-decked craft, and the viaducts form crossings over the railroads. In either case the structure is frequently enveloped in clouds of gas and vapor. That portion of the structure below the floor line receives this combined gas and vapor, with an amount of fine cinders which is blown against it with con-

Mr. Artingstall.

siderable force and in a heated state. This action appears to be much worse in the case of viaducts than in that of draw bridges, due probably on the one hand to the custom of tugs of dropping their stacks and shutting off the draft when passing under a bridge, and on the other hand to locomotives standing under viaducts and to the nearness of the top of the stacks to the viaducts in many cases. Chicago has yet to find a paint which can withstand this action with any degree of satisfaction. Tests were made with various paints furnished the city by manufacturers, and while some showed much better lasting qualities than others, none could withstand this action for any considerable length of time. Of all tested, red lead paint and a certain graphite paint showed the best results. At present the city is trying the method of forming a ceiling on the under side of the structure of 1-in. dressed and matched boards. This method promises very well, and aside from the first cost may prove a cheap and permanent protection for the floor systems of the viaducts.

For a number of years the city has, with some exceptions, used the following specification for the painting of both bridges and viaducts: First coat, to be put on in the shops, pure red lead and pure boiled linseed oil; second and third coats, to be put on after erection, oxide of iron and boiled linseed oil, in the proportion of about 8 lbs. of the oxide to the gallon of oil. In some instances the priming coat was pure boiled linseed oil only, and in others a metallic paint. However, after trying many substitutes for the above specification, it has been returned to in each case as giving the best results under all conditions.

While agreeing with the author as to the prime importance of a clean metal on which to paint, and the necessity of a good quality of oil whatever the pigment to be used, the writer does not think the investigation has been an entirely impartial one. It is not a difficult matter to collect data to prove the superiority of almost any reasonably good paint. Such a thing has often been done by manufacturers. A great amount of data and any amount of testimony could readily be collected to prove the superiority of red lead as a paint for iron work.

The writer's experience with paints and his tests of them tend to disprove some of the conclusions reached in this paper. He has not found the oxide of iron paint to withstand the action of gases and vapors from locomotives better than red lead, but the reverse. While agreeing that of the cases cited the iron oxide paint was usually tougher than the red lead paint, he does not think the oxide paint was otherwise in as good condition. He finds that the oxide paint is much more liable to pit and scale than the red lead. In several bridges examined recently which were painted with iron oxide, he found them badly pitted and scaled. His reasons for using the oxide paint for the

last two coats and for field painting generally are not because of a belief in the superiority of this paint, but because of the inconveniences connected with the use of red lead paint for this work, and of the difference in the cost of the two paints. Mr. Artingstall.

R. MONTFORT, M. Am. Soc. C. E.—While the writer fully concurs with the author that sufficient attention is rarely given to the removal of rust prior to the application of paint in bridge shops, his experience as to the lasting and protecting qualities of paint composed of pure red lead and linseed oil compared with iron oxide and linseed oil paints is in favor of the red lead. Mr. Montfort.

For ten years prior to 1883 the Louisville and Nashville Railroad Company painted all of its iron bridges with red lead; the average time when it became necessary to repaint was from seven to eight years. In 1883, for economic reasons, it was decided to abandon the use of red lead and substitute iron oxide, which was much cheaper. As a result, it was found necessary to repaint bridges every four years, on an average. There were cases in which great care had been taken in the original painting and in repainting, where the iron oxide lasted for seven years. On the other hand, in exposed locations along the Gulf Coast, it was necessary to repaint bridges three years after their erection. They had received one coat of linseed oil at the bridge shops before being shipped, and two coats of oxide of iron paint in the field. In 1891 red lead was again adopted as standard.

A serious objection to the application of oil prior to shipment is that iron so coated is very apt to become covered with small particles of cinders in transit, which stick to the oil and form a rough surface beneath the two coats of paint subsequently applied in the field after erection.

A mixture of red lead and oil when applied alone is objected to on account of its color corresponding with the customary danger signal; it also has the objection that it fades and gradually becomes white. To overcome these objections, 1 oz. of lampblack to 1 lb. of red lead is added to the last coat, which produces a dark chocolate color.

On old bridges that were painted once or oftener with red lead, and afterwards repainted with oxide of iron paint, the red lead appears to adhere well to the iron, and can readily be examined by scraping off the iron oxide paint; it can also be seen in many places where the iron oxide paint has worn through and rubbed off.

The writer never found any structure suffering seriously from rust beneath the paint that did not show rust through the paint. In old structures all rust should, of course, be removed as far as possible with steel brushes before repainting. It appears that steel is more liable to rust than iron. The results obtained from any kind of paint depend to a very large extent on the character of oil with which it is mixed and the care with which it is applied.

Mr. Howe. W. B. W. HOWE, M. Am. Soc. C. E.—The adaptability of any particular paint for the preservation of iron exposed to the weather is not likely to be determined by the examination of structures treated with it, unless complete information is at hand concerning the condition of the surfaces when painted and the ingredients of which the paint is composed, as well as their freedom from injurious adulterants.

The experience of the author, as far as it relates to the use of red lead, is so at variance with the writer's that the latter feels there must have been something wrong with the red lead, either in the pigment itself or in the method of applying it. The value of red lead as a paint for iron structures has been established the world over by both careful experiment and actual use. He has found it the best paint for the primary coat. It is an expensive paint and is frequently adulterated with substances that are themselves injurious to iron, and the difficulty of applying it properly probably leads to the work being done imperfectly at times. He has yet to learn of an instance of failure of pure red lead properly applied. He has used it largely in priming galvanized iron and with greater success than attained with any other paint.

Mr. Wilson. JOSEPH M. WILSON, M. Am. Soc. C. E.—The paper is a valuable one in that it contains reports of actual results from the use of the various paints in question, extending over a period for several years, and no amount of theory can equal practical experience. The writer has made use of red oxide of iron paint in his practice for 35 years with very satisfactory results, especially for girder bridges and other work that for æsthetic reasons was not required to be painted in light-colored finishing paints. On one prominent railway line this paint was used exclusively for all bridges, and his attention has never been drawn to any bad results from its employment. It is possible that there are, as with all paints, material differences in the quality of various brands, depending on the mode of manufacture and adulterations or in the methods of application, and the same is true for red lead. He does not think that the case has been proved against red lead so as to justify those who have been in the habit of using it in giving it up. But few cases of red lead appear to have been examined, and there is not the certainty in these that the material used was of first quality that obtains in most of the cases of iron oxide. Both materials are, in his opinion, good, although cheapness and ease of application are undoubtedly in favor of the iron paint. Of course everything depends upon the proper quality of the material, and with red lead there is more chance of deception in this respect and more inclination to add improper ingredients, for the purpose of increasing the facility of application, than there would be with iron paint. He has, however, seen iron oxide that after a few years will rub off like whitewash.

In his experience he made use of red lead for priming as long ago

as 1860. The first iron bridges built by the Pennsylvania Railroad Company were on the Pittsburgh Division in the original construction of this road, and had a priming coat of a tar paint (composition unknown), which after some years of service (probably 15 or 20 years) was found under the other paint, which had worn off, in excellent condition. Mr. Wilson.

He considers it of prime importance that the material should be protected with raw linseed oil, even before manufacture, especially if standing exposed to the weather, and that a coat of the same be put on after manufacture, and thoroughly worked into all joints and openings, the iron being previously scraped clean from all scale. The oil should be put on when the temperature is not lower than 60° Fahr.

A. E. Hunt, M. Am. Soc. C. E.—The writer agrees with the general position taken, that oxide of iron is the best paint for metal structures, if pure oxide of iron is used as the pigment of the paint and if enough is used to give good coloring matter to the rest of the pigment. Calcium sulphate is a material largely and to the best advantage used with oxide of iron, in at least equal proportions with the oxide of iron. Very many good paints are made with only 35% oxide of iron. He would suggest a minimum of 35% oxide of iron in the paint. A small percentage of calcium carbonate is advantageously added to neutralize the acid there may be in oxide of iron paint, but the proportion should not be over 5%, nor indeed should any other similar substance be used in large quantities, that will decompose by weathering. Mr. Hunt.

His experience is that much of the rusting under and flaking off of iron paints has been occasioned by the very poor quality of the paint used in the past. Much of it has contained free acids, which caused corrosion of the iron under the paint, due to the influence of this acid in the pigment, and much of the flaking off of the paint has been occasioned by the decomposition of the salts, such as carbonate of lime, in the pigment of the paint. Calcium carbonate in the shape of powdered limestone is a cheap substance to use in paints, and in some paints of inferior quality large quantities of it are used. Such paint he has found to be very poor and to last but little time without decomposition. A considerable amount of adulteration of linseed oil has been made in the past by means of turpentine or petroleum products, such as benzine, and these additions have always been to the detriment of the oil. Pure linseed is without doubt the best oil to be used for painting structural iron work.

G. H. Thomson, M. Am. Soc. C. E.—A corrollary from an ancient law referable to matter and its conditions reads: "Fire is a destroyer of conditions," and is applicable, in the prevention of rust, in the preparation of iron and steel prior to painting. Rust is a hydrated oxide of iron. Paint over rusted iron, and oxidation still continues under the paint. If fire is applied to the rusted metal, so that all Mr. Thomson.

Mr. Thomson. the water is driven out of the rust, and the metal then painted, the rusted iron will not oxidize further.

Old bridges badly rusted can be cleaned by this method. The rust can be loosened by kerosene oil, and the application of the torch will burn out all the kerosene oil as well as change the yellow (hydrated) oxide of iron to the red (anhydrous) oxide. In using the torch for cleaning old bridges, the writer has found it to be slow and therefore expensive, but effective. Eye-bars when removed from the annealing furnace can be painted as soon as cold, instead of leaving them on the ground for weeks to absorb moisture, resulting in incipient rust.

The preparation of metallic bridge work for painting is worthy of much consideration for future work. The expense stands in the way. If the old-fashioned method of pickling is adopted, tanks of long dimensions will be required. If the iron be cleaned by hand torches, the expense is one of labor, or time, alone. A scheme for shop fire cleaning by gas jets will reduce the labor of torch cleaning, but its cost is problematical. The expense of either method will not find much to encourage its adoption by railroad managers at present.

Mr. Randolph. L. S. RANDOLPH, M. Am. Soc. C. E.—In painting locomotive tanks considerable trouble is caused by rust forming under the painted and varnished surfaces. There was a tradition among the painters that a rust spot having been once formed, it could never be eradicated sufficiently to prevent its continuing to form rust, even after it had been painted over. The writer's observations satisfied him that the rust spots could be very readily cleaned so that there was no danger of further trouble from each individual spot. The idea of their being ineradicable probably arose from the minute cracks which formed in the painted surface, admitting moisture which was formed by condensation on the surface of the tank. The service required from a paint on the tank of a locomotive is probably more severe than that required of a bridge paint, notwithstanding the greater care which can be taken in painting the tank.

In regard to the relative durability of lead and iron paints, the writer's observations coincide with those of the author in that the iron paints are far more durable than lead paints when exposed to the weather. The action of the iron oxide seems to be to protect the leather formed by the linseed oil from the weather. Following up this idea, it has seemed to the writer that a paint used for this purpose would give most excellent results if sanded, as is frequently done with the external woodwork on houses.

Iron paint is the easiest to obtain pure. It is too cheap, as a rule, to be adulterated to any very great extent, and as the linseed oil is the most important part, it can be purchased in the paste form, the oil being bought separately. A little practice will make anyone quite expert in detecting adulterations in linseed oil. The writer has found that the

presence of iridescent bubbles on the surface of the oil, when shaken, almost invariably indicates the presence of either resin oil or a petroleum product, which are the most dangerous adulterations likely to occur. Of six samples of white lead bought several years ago, only one deserved the name of white lead, as it alone contained lead hydroxide. Mr. Randolph.

A. S. RIFFLE, M. Am. Soc. C. E.—The author's investigations bring out some interesting and decidedly important facts. Doubtless every engineer engaged in structural iron work has his own decided opinions regarding iron preservatives, strengthened, perhaps, by years of experience. The test conditions, however, are so varied that a consensus of opinion is scarcely to be expected. The author has struck the keynote in stating that the condition of the metal before the application of the primary coat is even more important than the quality of the paint. The writer's experience during several years' engagement as engineer of bridges on the western division of a transcontinental line, during which time he personally supervised the construction of many new structures and the repairs of a few old ones, confirms the conclusions of the paper in many particulars. During his connection with this road, the iron for a few of the bridges was oiled before leaving the shop, and in these cases it was found to be in exceptionally fine condition, never requiring the use of the wire brush, which was usually the case with iron which had been painted. Paint covers a multitude of defects, and corrosion is one of these. The writer has always advocated the use of oxide of iron in preference to lead paint, not because the latter was without merit, but because the former possessed more nearly those qualities which are required of a metal preservative. In stating his preference for oxide of iron paint, he does not wish to be understood as accepting as desirable every mixture masquerading in the market under the pseudonym of "durable paint," for these are scarcely less numerous than the structures they cover. An iron paint prepared from carefully roasted iron ore is certainly more likely to be free from injurious elements than one which has not been so treated, since by this process carbon dioxide is expelled and oxygen absorbed, thus precluding any possibility of further change by exposure to atmospheric or chemical action. When properly ground it mixes well with oil, a great advantage over lead, which cakes so readily that a uniform distribution is almost impossible. A paint to fulfill the many requirements, must possess many certain and reliable qualities. It must be elastic, yielding readily to the expansion and contraction of the metal; must not blister, scale or crack; must contain no injurious chemicals, and at the same time be non-absorptive to rain and moisture; must adhere tenaciously to metal under various atmospheric conditions; in fact, must have an almost unlimited number of virtues and no faults. No Mr. Riffle.

Mr. Riffle. doubt every engineer is thoroughly sincere in his advocacy of his particular kind of paint, but a pigment that has shown excellent qualities in one place might be utterly worthless in another.

Several years ago the writer was engaged to make an examination of bridges on various roads in a South American republic, an English syndicate having acquired them by lease a few years before. An examination found the bridges on two of these lines in a most deplorable condition, although they had been painted frequently since their construction 20 years ago. On one line a bridge consisting of 27 iron Pratt trusses, each of about 80 ft. span, was almost destroyed by corrosion. The end suspension rods, 1 in. square and one per truss, were in a majority of cases reduced in cross-section by corrosion fully one-half, in some cases even more. There was scarcely a member in the 27 spans that was not seriously impaired beyond the limit of safety. Another bridge of 4 spans, each of about 100 ft., was in about the same condition. On another line a 200-ft. through Fink truss, built by the old Baltimore Bridge Company, was found to be similarly affected. In several places the main diagonal bars, running from the center panel to the end posts, were almost perforated. These bars were about 1 x 5 ins. and no difficulty was experienced in picking holes over ¼ in. in depth in many places with an ordinary pocket knife blade. These bridges had been painted frequently, but with what kind of paint the writer did not at the time ascertain. These bridges were exposed to particularly trying atmospheric conditions. Owing to their peculiar location they were at times exposed to heavy, protracted fogs, then again to the intense heat from a tropical sun, and at all times to the salt breezes of the Pacific. On another line an examination of 17 iron bridges found them all in excellent condition, although some of them had not been painted since erection, nearly 20 years before. However, on this road the atmospheric conditions were such as to render corrosion to any great extent impossible. Rain was almost unknown, and the temperature of the atmosphere scarcely varied more than 25° or 30° during the year. The remains of the old Verrugas Viaduct on the Callao, Lima and Oroya Railroad in Peru, which the writer replaced with a cantilever bridge for L. L. Buck, M. Am. Soc. C. E., its chief engineer, was found to be singularly free from corrosion excepting pins and bolts, although it had not been painted since its erection in 1871 by Mr. Buck.

These illustrations serve to show that paints giving excellent results in one locality would be wholly inadequate in another. The paint which stands the test under the most severe and varied conditions is certainly the best. In closing, the writer must say that he is scarcely prepared to condemn lead paint for iron structures, having used it but little; but from his experience with oxide of iron, he has no hesitancy in continuing its use, believing it vastly superior to any other paint in the market.

A. F. ROBINSON, M. Am. Soc. C. E.—From a careful reading of the paper, the writer has arrived at the following conclusions as to the protecting power of the paint in the cases noted by the author: *First*, of the 34 structures painted with oxide of iron, 48% rank as good, 29% as medium and 22% as poor. *Second*, of the eight structures painted with lead, 71% are good and 29% are medium, while none are poor, notwithstanding the fact that in case of the Winona Bridge the paint was not properly applied. Mr. Robinson.

White lead, as used for marking iron at the shops, is ground in oil, but it is thinned with turpentine or benzine before use. The large proportion of drier thus added would be apt to make the paint brittle and easy to rub off, as has been mentioned in the paper in several places.

In 1884 the writer did the inspecting for some 75-ft. through plate girders that were erected in Kansas. The iron received one coat of paint (Williamsport, No. 31) at the shop and one after erection, and has been painted perhaps once since then. Before receiving the first coat the iron was thoroughly cleaned with steel wire brushes, all spots of hard scale being oiled and scraped before painting. This work was erected during July and August, and no painting was done in damp weather. At present writing all the horizontal members are quite badly rusted on both sides, the spots or blotches showing in much the same manner as described by the author.

A railway viaduct just east of Kansas City, over two other railway tracks, was built in 1887 or 1888 and had two coats of common iron oxide paint. When examined last September, this structure was very rusty, there being almost no signs of paint left, and the rust appearing in large patches all over the work.

During the past season the writer examined some iron bridges in Mexico near the Gulf Coast, where the atmosphere is full of moisture at all times. In the dry season a very heavy dew falls almost nightly, and this covers the iron work with moisture. Part of the bridges were painted with "Cleveland iron-clad" paint at the shops and some with other iron oxide paints; they were all repainted three or four years ago, but without scraping or brushing. When examined, this paint was soft and spongy and could be very easily scraped off. Under the paint the iron was quite rusty, though the rust spots did not always seem to be active. In some of these structures the paint had turned very black on the surface, and under this coating it did not seem to be soft or spongy as above. On structures farther from the coast and at higher altitudes, where the air holds but little moisture, the iron oxide paint was doing better, though the pimples and blisters with rust spots underneath, were quite common.

In the 75-ft. through girders above noted, the iron was as clean as it could be made without some special treatment, such as oiling at the

Mr. Robinson. rolling mills or pickling, and still the paint (iron oxide) did not protect the iron properly. In the other special cases mentioned, the iron oxide also failed to a greater or less degree.

A lot of rails which had been painted with red lead were taken out of the foundation for a proposed building at the site of the Woman's Temple, Chicago, Ill. The writer was informed these rails had been laid for seven years, but the iron was still bright and fresh under the paint.

Lead is seldom properly mixed for the first or priming coat at the shops, and it is not always used while freshly mixed. Lead paint requires much more rubbing or brush work than iron oxides, and the want of this may be one cause for the rust spots appearing.

Last year the writer had charge of the painting of a 150-ft. span which had received a coat of oil at the shops. Red lead paint was used and 1 gall. covered an average of 930 sq. ft. in first coat and almost 1 200 sq. ft. of surface in second coat. The paint was mixed fresh and 33 lbs. of lead were used for each gallon of oil. The writer has never been able to obtain an iron oxide paint that covered more than from 500 to 900 sq. ft. of surface per gallon. Lead paint properly mixed and applied may not protect iron work completely, but it seems to the writer that it can hardly do worse than the iron oxides.

Mr. Nichols. O. F. NICHOLS, M. Am. Soc. C. E.—It is true that oxidation and decay are certainties of existence which may be checked but cannot be prevented. On reading the paper one is astounded that the best bridges are so poorly protected after so many generations of painters have died firm in the faith that metal structures can be protected from such rapid oxidation. There are many things not understood about oxidation as well as about paint. Why, for instance, should steel oxidize less rapidly and differently from iron, and why should light iron, as thin sheets, band iron and steam pipe oxidize more rapidly than other forms?

If incipient oxidation did not set in, it would be wiser to leave the materials unprotected until they reached the bridge site, and the remarkable condition of the guard angles on the Alton and the Bellefontaine Bridges would seem to prove this a wise method, notwithstanding its condemnation by general experience and common sense. The only advantage gained is the removal of mill scale and the like by the constant jarring and handling of shipment. It is probable, however, that the incipient rust which must occur at some time begins at the mills and never stops when once begun. The author's proposed method of dipping pieces in oil is logical. One, if not the chief objection to the use of an oil coat, is the difficulty of knowing when it has been applied; the ordinary suggestion to make sure of coating, is to use a pigment and this naturally leads to paint.

That many things are not clearly understood, or are still open to dis-

pute or left to theorizing, is evident at many points in the paper. It seems, for example, more probable that the quality of the material or workmanship in the painting should vary in the several bridges, than that so many of the defects found should be ascribed to failure to clean the structures or to the presence of scale. That the metal had been rolled smoother for the Sioux City Bridge seems also a singularly fortunate ordering for this bridge. Although the paint had about all gone from the cylinders of the Floyd River Bridge, there was little rust, which would seem to demonstrate the folly of using paint in such situations. Exception will certainly be taken to the statement that rust which has not begun to pit will do no harm even if covered up by paint. Mr. Nichols.

Why should a pure oxide of iron paint be purple; and why, being pure, should it fade to the color of shoe blacking? Longitude, or the proximity to salt water, has quite as much to do with permanence of paints as latitude, and structures near the Atlantic coast are in a far more hazardous condition than those located in the great central valleys. The writer does not care to place himself distinctly on the side of red lead as positively as the author has placed himself on the side of iron oxide. The theory, and to some extent the observations, of the writer have been that the iron oxide paints have been less criticised and have appeared at their best because of their color and composition. If an excess of oil exists in the paint it is taken up by the oxide existing on the iron, and as oxidation takes place it has substantially the same color as the paint.

In 1886 he learned of an iron oxide paint made to compete with red lead, from an imported red oxide of iron costing about $50 per ton, when the material for "Prince's metallic paint" was selling at about one-third the price. This paint had been applied to the elevated railroad structure over the New Haven yard in New York City in 1885. Three coats were probably applied, one in the shop and two in the field; the situation was particularly exposed, but the structure has not been repainted since, and is to-day in very fair condition. The same year the old Brooklyn Elevated Railroad structure, 7 miles long, was painted with another iron oxide paint, of whose quality the writer has no knowledge, and he thinks two coats only were used—one at the shops and one in the field. The Brooklyn structure was badly rusted within four years, showing how much depends on the quality of iron paints. The writer once asked a prominent bridge manufacturer what paint he used, and he said he had but one rule: never to use a paint costing less than 75 cents a gallon. With linseed oil at 50 cents a gallon, even oxide of iron paints vary in price from 20 cents to $1 a gallon. One of the most serious objections against the use of oxide of iron paint is the uncertainty of knowing what is obtained, even at the higher prices.

The experience on the Suburban Stem Line structure, now part of

Mr. Nichols. the Manhattan Elevated Railway system, seemed to indicate decided merit in the paint used there, and in providing for new structures in Brooklyn in 1888 it was specified that the paint should be red lead for the shop coat, which had been used in 1887, or the special brand of red mineral paint referred to; the latter, being much the cheaper, was used. As a result, few people have so many acres of rust on exhibition as the citizens of Brooklyn, and it is beyond question that the structure painted with red lead in 1887 is in quite as good condition as that painted with red mineral paint in 1888. Both paints were followed by a second coat of white lead and zinc in light color. It is probable that a third coat of paint would have given much greater protection. The structures seem at first uniformly pitted, and this pitting in bad cases extends finally over broad surfaces, involving ultimately the whole member. The statement that plates are less affected than shapes seems, in this case, to be untrue, and the opposite more nearly the case, since the channels are rarely badly rusted, while the web plates are generally in this condition. The condition varies materially in different girders and seems to depend more on the care in the application of the paint than on any other one thing. Adjacent girders will be, one good, the other bad, without any apparent reason other than such as may be drawn from indefinite theorizing.

The difference in oxidation is marked. Such a thing as "rust under paint," as the writer understands the expression in the paper, is unknown with the red lead paint, which sticks to the iron with remarkable tenacity and always seems tough and keeps the iron bright, excepting where it has been badly eaten by the iron rust. When eaten through in this way the margins about the rust areas are quite sharply defined, while with the red mineral paint the old paint above and about the rust spots seems to loosen up into a sort of spongy mass, forming a cover to small spots or a margin to larger ones.

It is to be regretted that the author's investigation has been so generally confined to structures painted with red oxide of iron. He has evidently found but one case of fair painting with red lead. Some of the Cincinnati Southern bridges should be compared with those at Cairo and at Memphis, age for age, and latitude for latitude, and more should be known of the results of the general use of red lead by European engineers before condemning it in favor of some particular brand of red mineral paint.

Mr. Collingwood. F. COLLINGWOOD, M. Am. Soc. C. E.—The paper confirms in a remarkable degree the conclusions of other observers. In every case the author finds that where the protected surfaces were thoroughly cleaned in advance, the iron is in a better condition than where this was neglected or carelessly done. The peroxide of iron cannot by itself rust other iron, but it will hold more or less moisture, and should it be covered in this condition, the oxidation may continue after paint-

ing. It tends also to roughen the surface and prevent close contact of the paint with the surface of the iron. Paint in this condition will surely crack in time, and then the rust that has been covered will absorb moisture and act as a center from which rusting will continue. Mr. Collingwood.

In a paper by Mr. E. Matheson, published in 1882,* he says: "It cannot be too forcibly stated that it is impossible to protect rolled iron by paint without the removal first of the black oxide scales on the surface, and it is interesting to know that this preliminary process is an advantage also in steel." In the subsequent discussion he stated that "undoubtedly if the black scale could be permanently retained on iron it would assist in protecting it, * * * but the scale would not adhere unless the iron was absolutely protected from the air, and paint applied outside the scale became loose with it in a year or two." Mr. William Parker, Chief Surveyor of Lloyds, in a paper on corrosion says also: "Steel or iron should have the black oxide removed, to prevent galvanic action and pitting (in boilers)." He states also that the unequal distribution of manganese in steel probably acts in the same way.

In 1873, the first anchor bars were prepared for the New York and Brooklyn Bridge. The forging of the eyes left a very heavy scale upon them, and this was removed by hammers. They were then pickled in dilute sulphuric acid, next dipped in hot lime water and scoured with brushes, and finally painted with raw linseed oil, followed by boiled oil and iron oxide paint. The coating with raw oil not only covers the surface and penetrates any cracks or inequalities, but it tends to reveal defects instead of covering them up.

Much has been said about the injurious effect of sulphur in paints upon iron, and it is possible that this feeling is carried too far. It has always been understood that the sulphurous gases from the combustion of coal were among the most destructive agencies in their action. It would seem, therefore, that a paint which was itself a sulphate would certainly resist this action upon itself, and if it was inert toward the iron, that it would be an eminently fitting substance to use as a protection.

About 17 years ago a new paint was introduced in England, the principal constituent of which was the sulphate of zinc. In a paper read at that time,† the following statements were made: First, its covering powers exceed by 25% those of the best lead paints, without additional cost; second, it does not yield to the influence of injurious gases; third, it will not blister or crack under the action of the most violent heat; fourth, it contains no poison, and has no odor; fifth, it produces no chemical or galvanic action on metals. The article states that "the paint acts as a true preservative, and does

* See the *Proceedings* of the Institution of Civil Engineers, Vol. LXIX, p. 11.
† See *Engineering*, Vol. XXVI, p. 222.

Mr. Collingwood.

not yield to the influence of oxygen, ammonia, sulphureted hydrogen, salt or any other destructive and corrosive agent," and that these statements are endorsed by a number of eminent chemists and others. A notice of the works a year later shows that the consumption of this paint was rapidly increasing and the works were undergoing enlargement. It seems strange that a paint promising so well should not have been introduced here, and it would seem worth the while of those interested in obtaining the best possible preservative for iron work to look up its subsequent history and see whether it sustains the claims made for it.

Mr. Bontecou.

D. BONTECOU, M. Am. Soc. C. E.—The paper has great interest as a definite statement of experience to engineers who are charged with bridge maintenance, and is presented at a time when attention has been widely attracted to the unsatisfactory results of usual methods of painting. Previous to 1892 the Kansas City, Fort Scott and Memphis Railroad Company had been using a standard brand of iron oxide paint, which did not prevent rust from showing within three years, and the use of red lead was resorted to. The experience of the company with the latter paint is short, but, so far, more satisfactory. In the summer of 1892 six new spans were painted with a red lead priming coat and a "Prince's mineral" second coat, the work having received only a coat of oil in the shop. The paint has been efficient so far, except on the central portions of the overhead bracing, where coal gas has produced small blisters and incipient rust spots; elsewhere the steel is free from rust under the paint, and there are no signs of failure of any kind.

In order to determine the effect of coal gas on paint five pieces of iron were cleaned, painted and exposed for one year under a bridge of the Kansas City Belt Railway and over a main track, with the following somewhat indefinite results:

No. 1.	Carbon paint..3 coats	.....	Paint nearly gone; iron badly pitted.
No. 2.	Carbon paint..1 coat	next to metal...	Paint and metal smooth; slight amount of rust under paint.
	Iron oxide.....1 "		
No. 3.	Red lead.....1 "	next to metal...	Iron paint gone; lead paint good; metal smooth.
	Iron oxide.....1 "		
No. 4.	Red lead.....2 "	.....	...Paint fair; iron very slightly pitted, and small amount of rust under paint.
No. 5.	Iron oxide.....2 "	.....	Paint gone; iron badly pitted.

It will be seen that the first two and last cases present an anomaly, which can only be explained by the fact that the painted surfaces were only about 19 ft. above the track, and the impact of the cinders from the engine, which was working on a grade, may account for the failure of the carbon paint in case No. 1.

In order to rest conclusions about red lead on a broader ground, the writer communicated in 1894 with a large number of chief engineers

and bridge superintendents who were in a position to have formed opinions of value on the subject. The correspondence developed the fact that the use of iron paints had been considered unsatisfactory in many quarters where red lead was being used and thought to be distinctly better than the iron oxides; while some of those addressed were able to cite definite cases, from their own experience, where red lead had prevented rust for very long periods. Mr. Bontecou.

The paper renders a valuable service in pointing out the importance of applying the first coat of paint to a clean metal surface. Probably most engineers will agree that a shop coat of oil only is best, and that painting over rust will account for many failures. The inference that any good pigment will protect the metal as long as the paint lasts, however, seems to the writer to be misleading, because it rests on another conclusion, that rust found under paint has been there from the time the paint was applied. As rust develops under an inferior paint, breaking out first where the exposure to sun and water is most severe, it is fair to conclude that such paint is pervious, and that even if no rust existed on the metal when the paint was applied, the oxidation would, nevertheless, take place in time. It is not enough that the paint should be hard and tenacious, for if it does not prevent rust these qualities detract from its value by increasing the cost of repainting.

It is probable that final conclusions as to the efficacy of different pigments can only be reached by observing results where all the conditions are known, and if a paint can be selected which will admit of increasing the intervals between repainting bridges, the cost of the paint itself will not be an important element of the case. A good many difficulties about red lead are alleged which, from the standpoint of a somewhat limited experience with it, seem to be overstated, and there is no real difficulty in procuring pure materials or applying them properly and economically.

J. E. GREINER, M. Am. Soc. C. E.—If the statement is accepted that the oxide of iron paint does not cause the iron under it to rust, the author has succeeded in exposing a fallacy. All are aware, however, that a little rust spot, which is oxide of iron, has a tendency to develop into a large rust spot, and as the oxide of iron paint is merely rust mixed with oil, it would appear that there was some foundation in the belief that this kind of paint produces rust on an iron surface. But whether the oxide of iron paint causes the metal under it to rust or not, there are objections to it which can be readily ascertained by any one who will take the trouble to make an inspection over the lines of any railroad which has been using it for the last eight or 10 years. Where one bridge is found the paint of which has stood unimpaired for a period of four years, a dozen bridges will be found which have been painted every two or three years, the paint having apparently dried up and washed off, leaving the iron almost bare. Mr. Greiner.

Mr. Greiner. The good paint and the bad paint are put on by responsible bridge manufacturers, as meeting the usual specification requirements, and the expression used by the author, in his condemnation of red lead, "if it is impossible to buy an honest article of the specified kind, endeavors to get it had better be abandoned for something we can be sure of," would apply more effectively to the oxide of iron paints than to the red lead paints, as the latter can be obtained free from impurities and mixed under personal supervision, without any adulterations whatever, except the addition of a little lampblack, which has beneficial effects. The author's failure to find but a single case where the red lead adhered well or was tough would indicate that in this single case the red lead was pure and mixed with pure linseed oil, properly applied without adulteration. There is no assurance whatever that the other paints which he has classed as red lead paints were of the right quality and prepared in the proper manner, as he himself admits.

Considerable stress has been laid upon the discovery that the white lead mill marks remain on iron, and that red lead, as a general rule, is brittle and easily removed, but it is to be particularly noticed that while they may have been brittle and easily removed, rust spots were rarely found in such cases. This would indicate that the mere fact of the paint becoming somewhat brittle after standing for a number of years is no material defect in itself. Another point that may be noticed here is that cases were discovered where certain rust spots which had become saturated with oil were inactive. In other words, the rust on the iron itself, when saturated with oil, became an iron oxide paint, and protected the metal against further rust. If such is the case, it would seem that structures could be protected just as well by exposing them to the weather for a couple of years, so that they would get a good coat of rust, and then smear some oil over this rust; this would, at least, give an oxide of iron paint, and from the evidence advanced one would be led to suppose that such a treatment would have just as good a result as though the metal had been thoroughly scraped, then covered with a coat of oil, and afterward painted with great care with two coats of oxide of iron paint. It would also be cheaper.

While the writer's experience with red lead is limited, his experience and personal knowledge of the wearing qualities of oxide of iron paint, as ordinarily made, has extended over a sufficient period to have caused him to abandon the use of the latter paint entirely, as being practically worthless except for the sake of appearance immediately after being applied. It must be understood, however, that this statement is to be taken in a general sense, because there are some special brands of oxide of iron paint, sold as proprietary paints, in which the pigment has been very finely ground and pure oil used, which have given what can be considered fairly good results.

Mr. Greiner.

Some of the best results in the use of oxide of iron obtained on the lines of the road with which the writer is connected can be illustrated by the Susquehanna River Bridge, which was painted in 1886. In 1889, three years afterward, the span crossing the Port Deposit and Columbia Railroad was in such bad condition that it required repainting, and it was repainted with one coat of Prince's "metallic brown" and oil. In 1890 or 1891, from four to five years after the application of the first coat of paint, the entire bridge was repainted, and at the present time, three to four years later, the tops of all the chords are in bad condition, and the entire bridge will have to be painted within the year.

Another case, the Schuylkill River Draw Bridge, was painted at the time of the erection, in 1886. In 1890, four years afterward, it was necessary to paint the tops of the chords; in 1892, six years afterward, the entire bridge was painted. At the present time, the paint on the top chords, having stood about three years, is in very bad condition, and within the present year, or three years after the entire bridge was painted, the bridge will be in such condition as to necessitate repainting.

Another case which might be mentioned is the bridge at Grafton, W. Va. This was erected in 1891, covered with a coat of oil in the shops and painted with two coats of oxide of iron paint in the field. Two years later, in 1893, the paint was in such bad condition that the structure had to be repainted. At the present time the paint is in fairly good condition, except that on the tops of upper chords it is slightly blistered.

If any bridgeman be asked how long oxide of iron paint will last, he will be very apt to say it will last about two years, this being the general rule. Engineers' experience with oxide of iron paint has largely led them during the past few years to abandon its use, and substitute in place of it pure red lead with 1 oz. of lampblack to 1 lb. of red lead mixed with pure raw linseed oil, so that there will be from 10 lbs. to 12 lbs. of red lead to 1 gall. of paint. This kind of paint is becoming very general in its application, and where three or four years ago a large portion of the structures were painted with oxide of iron paint, it will be safe to say that at the present time, a larger portion are being painted with red lead. If it could be demonstrated by actual experience that the red lead is no better than the oxide of iron paint, but that it is just as good, the writer would still prefer the red lead because its covering capacity when mixed with lampblack is about twice as great as that of oxide of iron, and when properly applied the total cost of painting, including the paint, is no more per gallon than with the cheaper article.

At the request of the writer, some tests were recently made as to the covering capacity of red lead and lampblack, Burtis, Patterson &

Mr. Greine. Sargent Company's "carbon" paint, and Rinald Brothers' "Bessemer" paint, these paints being used on three different bridges in course of construction. The results of these tests were as follows:

RESULTS OF EXPERIMENTS WITH PAINTS.

	Red lead, 12 lbs.; lampblack, 10 oz.; mixed with pure raw linseed oil to form 1 gall.	Carbon paint; Burtis, Patterson & Sargent Company.	Bessemer paint; Rinald Brothers.
Paint, per gallon	90 cents.	$1 25	$1 50
Labor, putting on	50 "	0 37½	1 00
Covering capacity	600 sq. ft.	600 sq. ft.	720 sq. ft.
Cost per square foot	0.233 cent.	0.271 cent.	0.347 cent.

In connection with the above tests, it is well to bear in mind that the paint was applied by the regular force used for painting structural work at the bridge shop, without showing preference for either kind of paint, care being taken that the iron should be fully covered.

The writer has, during the last two years, examined structures which have been painted with graphite paint, and after four years' exposure, the paint was still in excellent condition. He has seen other samples of graphite paint which, after a few months' exposure, had much the appearance of alligator hide. Asphalt paint in several cases which came under the writer's notice, although of an expensive kind, became practically worthless after having been exposed for less than two years.

In the spring of 1892, some girders were painted with pure red lead and pure raw linseed oil. The writer examined these girders recently, and found that although but one coat of paint had been applied, and that three years ago the paint was just as glossy and fresh looking as though just put on. The ordinary oxide of iron paint, after standing the same length of time, almost invariably shows a dry dirty surface without any gloss or body and can frequently be rubbed off with the bare hand.

A little more or less in the first cost should cut no figure so far as paint is concerned, as it is the wearing quality and protection which is the object in view. Therefore that paint which will give the best protection for the longest period and has a good covering quality is the paint to use. The writer has been using pure red lead, pure raw linseed oil and commercial lampblack, which can be readily obtained, for several years, and while there may be certain preparations of oxide of iron or other paints of a secret nature equally as good, he can as yet see no reason for making a change.

Mr. Le Conte.

L. J. Le Conte, M. Am. Soc. C. E.—The writer agrees with the author as to the admirable qualities of pure oxide of iron as a pigment, mixed with pure linseed oil. It has all the requirements of a good durable coating and is economical. The recent tirade against this valuable paint is due entirely to adulterated articles which have flooded the market. The adulterant is an artificial oxide of iron, a waste product derived from copperas roasting, notably in the manufacture of sulphuric acid. This waste oxide is full of sulphur, can be bought for little or nothing, and the temptation to adulterate is too much for the average business man to withstand. As a result, it is almost impossible to get a pure oxide of iron pigment in California. Of course, the good name of any paint is liable to be ruined by the market becoming flooded with an adulterated article. The author's remarks about lead paints call to mind a paper written some 10 to 12 years ago in France, and published in *Annales des Ponts et Chaussées*, in which the opinion was expressed that in the case of red lead mixed with linseed oil the chemical action which takes place develops a certain amount of hydrochloric acid, which in turn attacks the iron work. This fact was determined by pricking the first blisters after painting and examining the fluid matter contained therein. This engineer recommended the use of white lead next to the iron, because experiments showed that when mixed with linseed oil the chemical action developed did not give rise to any form of acid. The writer's observations, though limited in extent, tend to corroborate these views.

Graphite paints are now largely used in California, and so far have a very good record for protecting iron work against rust. The material is absolutely inert, the paints spread to a remarkable degree, and the price is low. As far as experience goes, they adhere well and give every indication of being a very durable class of paints. In short, the writer thinks they are the only paints which stand on the same footing with the good iron oxide paints advocated by the author.

Asphalt paints have not made a good record on the Pacific coast. When applied under shelter they seem to do well enough, but when exposed to the hot, blistering sunlight they go all to pieces and leave nothing but a black powder behind. In extreme cases this disintegration has taken place within six months. The most remarkable fact recorded is how some of these paints successfully withstand sulphurous fumes and actual direct contact with fire in smokestacks, and yet, when exposed to the direct rays of the hot summer sun, they literally crack all to pieces, soon become a black powder and the coating is entirely gone.

Mr. Eayrs.

N. W. Eayrs, M. Am. Soc. C. E.—Without wishing to detract in any way from the credit due to the author for the care and fidelity with which he has made the examination of the structures mentioned in his paper, the writer ventures to question the accuracy of his conclusion

Mr. Eayrs. with regard to iron oxide paint. The fact is, the relative value of iron oxide paint and any other good preservative covering cannot be determined by a cursory examination. It is necessary to know the history of the structure, the climatic conditions to which it is exposed, and especially the condition of the metal before the covering was applied, as well as the quality of the paint used.

Since rust was found to a greater or less extent on all structures examined, without regard to the kind of paint used, it is a reasonable assumption that the metal was not perfectly clean when the structures were painted. If it be true, as the author declares, that if rust is "already well developed and of some thickness it will have enough oxidizing agents in its pores to develop more oxide, swell up and crack the paint," it is also a reasonable assumption that the iron oxide in mineral or oxide paints may have sufficient oxidizing agents remaining to continue the rusting process. Natural iron ore, free from sulphur, and ground either with or without roasting, combined with pure linseed oil, undoubtedly makes an excellent covering for metal. Many of the so-called "iron-clad" or mineral paints on the markets are, however, made of inferior materials, and may contain chemicals injurious to the metal. Such paints are made even by reputable manufacturers, and their constituents can only be determined by chemical analysis.

The true way to test the relative value of paints is to apply them under precisely similar conditions as to cleanliness of metal, exposure to weather and other influences, and care in applying the paints. Such a test has been made on a portion of the elevated structure of the Merchants' Bridge Terminal Railway of St. Louis, referred to in the paper under the title of the St. Louis Elevated Railroad. This structure was erected in 1891, from designs and under the care of the then chief engineer, Robert Moore, M. Am. Soc. C. E. At the foot of Wash Street, the elevated structure crosses the Wabash Railroad side tracks. Of the four girders in each of the three spans at this point, the two inner girders are painted with a carbon paint, and the two outside girders with a patent iron oxide paint, which was selected by Mr. Moore after careful analysis of several paints offered, and was used on the entire structure, except at Second Street. The writer is informed that these girders were carefully cleaned before painting. They are evidently exposed to the same corroding action of dampness, and of smoke and gas from locomotives passing under them. A recent examination of these girders shows that the external appearance of the paints was equally good. Both paints adhered well to the metal, although not as well as some iron oxide paints. The carbon paint was, however, more elastic and tougher than the oxide paint. A strip of carbon paint about 3 ins. long and $\frac{1}{4}$ in. wide, cut from the girder, could be rolled into a ball and unrolled several times without breaking, while a similar strip of the oxide paint would usually break on

the second rolling. No blisters or pits appeared on the surface of either paint, but a few spots were discovered under the oxide paint, the location of these being indicated by a slight difference in color. The metal under the carbon paint was found to be bright and clean wherever scraped. It is fair to assume, therefore, that there is no difference in the protective quality of these two paints, although the superior toughness of the carbon paint is a point in its favor. These girders were painted in the summer of 1891. Mr. Eayrs.

The carbon paint referred to is one that has been in use by the Terminal Railroad Association of St. Louis for more than 10 years. It is manufactured from a formula prepared by the master painter of that company, which formula was the result of an extended series of tests made to determine the best covering for the iron work in the St. Louis tunnel. It is made of pulverized charcoal, litharge and the best quality of boiled linseed oil, with the addition of a little borax water. It comes from the manufacturer in a semi-liquid form and is thinned for use with oil alone, no turpentine or drier being used. It is a slow drying paint, and never dries hard and brittle. Paint which had been exposed to the tunnel atmosphere for six years was found to be as elastic and pliable as when first applied. In 1892, the carbon paint was adopted as the standard for all metal structures, whether under ground or above ground.

The overhead crossing of Second Street by the elevated structure and two spans of trestle east of Second Street were painted with red lead and oil; the remainder of the trestle adjoining was painted with the oxide paint. The red lead is considerably discolored with rust spots, and the external appearance is much inferior to that of the adjoining spans. The surface is quite badly pitted with apparently active rust spots, much more so than on adjoining columns and girders painted with the iron oxide, but no worse than on some portions of the elevated structure on the levee, which is also painted with iron oxide. Where the red lead is still in good condition, the metal is clean underneath. It would be interesting to know what was the condition of these spans before painting; how they compared with other spans of the structure which were covered with oxide paint.

The author's remarks on the condition of the Merchants' Bridge in St. Louis are perfectly correct. The bridge is in very bad condition, especially the east span. Where the paint still adheres to the iron it is removed with great difficulty, but the writer is not entirely satisfied that the adhesion is not due to a partial chemical union with the oxide in the paint. In most places the covering is a very thin coat, and where large areas are covered with rust the paint seems to have disappeared through disintegration rather than by scaling off. The bridge will be repainted this spring with carbon paint.

Red lead and oil were used at one time to a considerable extent on

Mr. Eayrs. the girders which carry the upper roadway, or highway floor, of the St. Louis Bridge, but it was found that the heat from the locomotive stacks passing under the girders while the paint was still fresh, "killed" the oil and caused the paint to come off in large flakes soon after it was applied. The use of red lead has been abandoned and carbon paint substituted. This stands the heat much better than any other paint hitherto used.

Every engineer will agree with the author, that in order to protect metal structures to the fullest extent it is necessary, first, that the metal should be thoroughly clean before painting; and second, that the covering selected must be made of a good oil with suitable pigment. The metal should be cleaned and oiled in the shops, as it is impracticable to do this thoroughly in the field. The best quality of linseed oil only should be used in the manufacture of paint, combined with any good pigment which contains nothing injurious to the metal. The writer's preference is for carbon as a pigment for iron work; this contains no sulphur, while many of the iron oxide paints are made from pyrites which do contain sulphur.

Mr. Bouscaren. G. BOUSCAREN, M. Am. Soc. C. E.—Excellent suggestions are made in the paper with regard to the method and precautions to be used in painting iron structures, but it is to be regretted that the author's conclusions should be broader than his foundations. That "pure iron oxide used as a pigment in paint is not a cause of rust on metallic structures exposed to air" is a legitimate deduction from the numerous cases investigated by the author, where the composition of the iron paints used and the method of application were known. That "the present investigation fails to point to red lead as the one pigment above others for painting iron structures exposed to air" is undoubtedly true and the reason obvious; red lead has not been investigated.

The author admits that in all cases of so-called red lead paint investigated by him, the composition of the paint and the manner in which it was applied were unknown to him. "No chemical analysis was made, and the authority for their genuineness is only the specifications, the integrity of the contractor and the color of the pigment."

Under such circumstances the probability is that not a single case of genuine red lead properly applied was examined. No weight can therefore be given to the comparison made between the two kinds of pigments, and the judgment passed as to their relative merit is misleading.

A great deal of attention was given to painting of iron bridges by the writer while in charge of the Cincinnati Southern Railway and associate roads for a period of 11 years, during which different kinds of paint were tried systematically under the same conditions and the same paint under various conditions. The results of these experiments were as follows:

First.—That an essential condition to the preservation of the metal under any kind of paint is that the surface be clean and free from scales and rust; no fair test can be made otherwise. Mr. Bouscaren.

Second.—That the best covering for the metal before leaving the shop is boiled linseed oil. It will penetrate all joints better without pigment, will not rub off as easily as paint, and will not hide defects which may have escaped detection at the shop. It affords a better foundation than dried paint or the bare iron for the subsequent painting in the field, as it readily incorporates with the first coat and prevents "running." The objection to the raw oil is that it remains sticky and gathers a large amount of cinders in transportation, which must be scraped off before painting.

Third.—That no painting should be done in rainy or freezing weather, otherwise materials and labor are both wasted. New structures, if thoroughly coated with linseed oil, will not suffer by waiting several months after erection for favorable weather to do the painting.

Fourth.—That the best results are obtained when the pigment is ground in oil beforehand. The practice of allowing the painter to mix the paint himself has led invariably to irregular and inferior results. The indiscriminate use of driers is another practice to be avoided. Boiled linseed oil should be the only ingredient used with the ground paint.

When all these conditions have been observed, pure oxide of iron has been found to protect the iron very well under ordinary circumstances for a period of three years, and red lead for a period of six years. Both adhere well to the iron and will not scale or crack. These effects are sure indications of impurities in the materials used, or that the iron was not well cleaned before painting, or that the work was done in an improper manner. Both paints should wear off gradually and uniformly until the coating is reduced to a mere film, when points of rust will begin to make their appearance, which will soon develop into blisters. A fresh coat should be applied before rusting takes place; this will avoid the necessity of scraping, which can never be thoroughly done on a standing structure.

A great deal of the oxide of iron offered in the market contains a large proportion of clay which renders it unfit for the purpose of painting. Chalk and lime are used freely to adulterate red lead, and the writer has personal knowledge of instances when not more than 20% of red lead could be found by analysis in the article delivered under that name for painting. These frauds can easily be avoided by dealing directly with manufacturers of good standing instead of buying from the lowest bidders.

True economy in paint is to use the best materials. As between iron oxide and red lead the writer has a decided preference for the latter, not only because it will last much longer, but especially because it is more uniform in good results.

Mr. Moore. ROBERT MOORE, M. Am. Soc. C. E.—In describing the viaduct built by the Merchants' Bridge Terminal Railway Company, in St. Louis, the writer mentioned* the fact that while the greater part of the structure was painted with iron ore paint, part of it was for purposes of comparison painted with red lead, and he expressed the hope that in a few years definite results of permanent value might thereby be obtained. A recent inspection of the present condition of the paint on this structure revealed the fact that although it is barely four years since the paint was first applied, by far the greater part of it should be renewed during the present year. And to the writer's surprise he found those girders which were painted with red lead to be scaled and pitted worse and to need repainting more than the adjoining ones which were painted with iron ore. As the red lead used was bought by the company for the purpose of a test, and as both paints were applied at the same time, and, so far as known, under the same conditions, the experiment is one of considerable value. There are one or two things, however, which make it not wholly conclusive. Of these the most important is the variable and uncertain condition of the metal when the paint was applied. At the shop all of it was coated with oil. But much of it lay afterward for months on the ground exposed to the action of dirt and water, and before it could be painted was much rusted. While an effort was made to clean it, it was but partly successful, like all efforts of the kind. This fact accounts for the present bad condition of so large a part of the paint and renders the experiment somewhat inconclusive. So far as it goes, however, it points to the superiority of the iron oxide.

As the author indicates, a thorough cleaning of the metal before painting is of the first importance, and for this purpose the writer has long been of the opinion that the sand blast would be extremely useful. It would be rapid and thorough and would reach corners otherwise inaccessible. And if once a portable apparatus were arranged, as could easily be done, it would be cheaper than hand labor. The mechanic who will put such a tool into the market will find a wide field for its use and will merit the thanks of all who have to do with bridge work.

Mr. Purdy. CORYDON T. PURDY, M. Am. Soc. C. E.—All who are to any extent interested in the preservation of structural iron work will welcome the data contained in the paper. In a recent paper, the writer stated† that iron oxide paint should not be used on structural iron. If the author's conclusion can be sustained, the writer will be glad to modify his, which is based on what he could get from the testimony of others and from his own limited observation, but the iron oxide paint, generally used on structural iron work required for buildings, so far as he has been able to observe it, is certainly not desirable, and much of it

* See the *Transactions* of the American Society of Civil Engineers, Vol. XXXI, pp. 500-508.
† See the *Journal* of the Association of Engineering Societies, Vol. XIV, p. 210.

Mr. Purdy.

is exceedingly bad. This examination indicates, however, that the purest and best iron oxide paint is not as bad a paint as its opponents suppose; though it seems as if the testimony in the paper did not warrant the definite conclusion that iron oxide paint is the best, or even that it is better than red lead. The bridges covered with iron oxide paint, which were most thoroughly examined, represent the very best that can be obtained, both in the character of the material and in the application of it, whereas little or nothing is known regarding the character of the red lead paint and the way in which it was applied. This is peculiarly significant when it is recalled that the way in which the red lead is used has very much more to do with its value as a paint than the way in which the iron oxide paint is used; indeed, if the former is not properly put on, its value as a paint is very largely neutralized. Again, it will be noted that many structures were examined which were painted with iron oxide paint, whereas only a few were examined where the red lead was used; also, that all the structures examined are in the interior where paint ought to protect iron if it will protect it anywhere, while if some of these structures had been along the coast, they might not have made as good a showing. At any rate it seems as if corrosion proceeded much more rapidly in salt air than in the drier interior. There are many illustrations about buildings in the vicinity of New York, where in 40, and sometimes even in 20, years rust has entirely eaten through and consumed $\frac{3}{8}$-in. metal.

The whole subject of painting, the characteristics of good paint, the preparation of the iron before the painting, and the proper application of the paint, are more important, however, than the one question whether oxide paint is the very best or not. The author's observations on these kindred questions cannot be made too emphatic. Mr. Morison can control the painting of his bridges in every detail, he can get the very best material, he can secure good inspection and honest work, he can be sure that his iron is clean before the work is done, and he can select his own time for doing it. His good judgment in the matter can control it all, but in many structures, some of them of considerable importance, this is not so, and the cheapest paint is the one that will be used. This lack of authority is especially true with reference to building work, a large part of which is designed without the services of an engineer, except such as may be employed by the contractor. The architect, in many cases, does not fully appreciate the importance of protecting the steel construction against corrosion, and if he does, the chances are that the owner of the building insists upon carrying out his own ideas, which are more likely to be in the wrong than in the right. If an engineer is associated with the architect, he labors under the same disadvantage.

The tonnage of metal going into large buildings has now become very great, and the importance of protecting it has correspondingly

Mr. Purdy. increased. It may be of some interest to the Society to know that all the steel required for the construction of the new hotel to be erected in New York by Mr. John Jacob Astor, must, according to the proposed specifications, receive a coat of pure raw linseed oil at the rolling mills before being allowed on the cars. The plans and specifications of the building have not yet been finally adopted, but there is reason to believe that this provision will be accepted. The building will be one of the largest ever erected in this country, requiring somewhat over 10 000 tons of structural metal. The graphite paint manufactured by the Detroit Graphite Manufacturing Company has also been specified in the belief that it is more to be relied upon than any other paint which could probably be secured for this particular work, if, indeed, it is not the very best which can be had anywhere. The selection was made after a very exhaustive examination into the matter, and on the basis of some extraordinary testimony, from those who have used it.

The author's examination shows quite clearly that rusting as a rule proceeds under paint, even under the best iron oxide paint that can be obtained. If a paint can be made that will cling closely to the iron and that will remain unbroken in all kinds of weather, in heat and cold, and that will not absorb and retain moisture, or in other words, that is entirely impermeable, it seems as if oxidation already begun could be stopped, and it also seems as if the graphite paint promises the most in this particular.

Mr. Melvin. DAVID N. MELVIN, M. Am. Soc. C. E.—Having used paints daily in large quantities during the last 20 years, the writer has observed some things in their actions and in the behavior of different compositions which may be of interest, both in bearing out some of the deductions of the author and in helping to find out the best protective paint.

Red lead he abandoned more than 15 years ago for all admixtures and purposes other than as a drier in boiling linseed oil, as he found that under certain conditions of temperature and moisture it formed a chemical combination with the oil, resulting in a body very much resembling sticking plaster. Iron oxide he has since then used invariably for outside use, for roofs, walls, etc. On more than 100 000 ft. of roofing painted with it, no oxidation or rust has been found under the paint, if the paint was in good condition; that is, had not been injured by walking over it or by other actions it was not intended to withstand. Several of the roofs have rusted through from the inside, but none from the exterior. At the joints where the tin has been soldered and the rosin has not been scraped properly, there has been considerable rusting caused by the paint scaling and cracking off.

Linseed oil has been invariably used to the exclusion of all petroleum products, turpentine or benzole, as these have been found to cause the paint to dry porous and eventually to become cracked; this applies to all kinds of paint.

Mr. Melvin.

The writer has used over 1 000 galls. of linseed oil daily for many years, prepared in several different ways, and has thus had an opportunity of watching the effect of the various methods of treatment. He has found a great difference in the skin of film formed by the drying of the oil, and upon the adhesiveness, permanence, strength and elasticity of this skin will depend very materially the lasting qualities of the paint made from the same oil.

When linseed oil is simply heated with about 3% of litharge or red lead and kept at a temperature of say 350° to 650° for five or six hours and agitated mechanically, or with paddles, as is commonly done, it is then called "boiled oil," and is used promiscuously for painting without any inquiry into the quality of the skin or film it would form when dried. Accordingly as the oil is treated with different driers and at greater or less temperature, and agitated by air blown through it for longer or shorter periods, so the quality of the dry film or skin it will produce is affected as to strength, elasticity, solubility, and other properties. By using a drier of salts or oxide of manganese and continuing the agitation of the oil by air blown through it, as in the Bessemer process, the oil being kept at a comparatively high temperature, say 450° to 500°, the skin may be made to become of a very strong, elastic and durable nature, and perfectly insoluble in either water or benzole.

There is a considerable difference in the albuminous and mucilaginous matter contained in commercial linseed oil, some oils containing nearly 1%, others considerably less, according as the seed has been pressed with hot or cold plates, the amount of pressure given, and the quality of the seed. As to the difference in the quality of commercial linseed oil (always supposing it to be unadulterated purposely) the variation in the amount of these mucilaginous substances or so-called "foots" is the only practical difference the writer has been able to detect; he always overcomes this by blowing air through for longer or shorter periods, and boiling at higher or lower temperatures, as the oil contains more or less foots. If these foots are not removed from the oil before it is used, the effect is to render the dried skin more pervious to moisture and the paint less permanent. Some oil crushers, realizing this, are now filtering these foots out so as to give a pure oil, but it is possible to get rid of them by heat and blowing, and as the oil has to be boiled in any case, one process serves all purposes.

All admixture of rosin, rosin oil, gums or linseed oil substitutes of any sort the writer has always found injurious to the strength and elasticity of the dried film, and the result is a friable resin like rosin, instead of an elastic gum like india-rubber. When a sample of a new oil or linseed oil substitute is submitted for examination, the writer always paints it on coat after coat until it becomes thick enough to judge of the quality of the skin when dry.

Mr. Melvin. Iron oxide paint has had the objection urged against it that it cracks and scales off. The writer never found it so, unless painted over unclean surfaces or mixed with too little oil and daubed on too thickly. If too much pigment is mixed with the oil, especially if the oil has little viscosity, the dry paint is without sufficient elasticity, and will scale off with any change of temperature. Viscosity has great effect on the cracking of all paints, as with a thick oil it is impracticable to put in as much pigment as with a thin fluid oil. With the thicker oil when it dries there is a thicker and more elastic film of oil between the particles of the pigment, giving more play for expansion. With a tolerably viscous oil, the writer has found that equal proportions by weight of oil and iron oxide pigment make a good paint, and he has never found it to crack or scale at this proportion. The manufacturer's analysis of the pigment he has used for the last 20 years is as follows:

Peroxide of iron	52.11
Carbonate of lime	0.27
Silica	46.03
Moisture, etc.	1.59
	100.00

Too great a proportion of carbonate of lime in any paint makes it more easily affected by moisture. Some mixtures made of paris white were so easily affected that they became quite soft every time water was placed on them.

Iron oxide has a drying effect on paint, but the effect is diminished as the amount of it is reduced in proportion to the other ingredients. In one mixture where the writer used the so-called Venetian red and had to use litharge as a drier, by substituting the cheaper oxide pigment he saved the litharge entirely.

White lead he has proved to have the least action upon linseed oil of any pigment of which he makes use; in fact, he can find no other white pigment which will take its place entirely.

Oxide of zinc is a powerful drier, and renders all paints liable to crack; for a paint of ordinary purposes more than 15% of it with white lead cannot be used without risk.

Sulphate of lead, or the so-called sublimed lead, the writer has abandoned altogether, as its action on the oil was very marked, probably from adulteration with zinc, as he had a very strong reaction for zinc in testing it.

Lithophone is a German sulphide of zinc and barium, which is the best he has yet tried, and he now uses about 3 tons per week of this to about the same quantity of white lead.

The covering power of lead paints is much overstated. Equal quantities of oil and oxide of iron make a good covering paint, while

it takes 4 to 1 of oil of either white lead or red lead to cover equally well with the oxide paint. This puts lead paints out of the question when price is to be considered. Mr. Melvin.

The writer sincerely wishes a perfect substitute could be found for white lead, as the poisonous effects on the workmen are very serious, manifesting themselves even after 10 years' absence from contact with it.

A. H. SABIN, Esq.—It is said by people who have much experience and are regarded as of high authority, that the life of a steel frame building is about 30 years, and it is generally agreed by bridge engineers that the most common cause of failure of bridges is the slow corrosion of the bridge members, carried on frequently under several coats of paint, which goes on until the structure becomes weakened below the limit of safety, when a portion must be replaced, or, if it escapes observation, the bridge breaks down. The failure of water mains and pipes to withstand the interior pressure is almost always due to corrosion, as these conductors are commonly strong enough when new to withstand many times the pressure employed, and any serious leakage is usually due to a considerable weakening of the pipe from this cause. Mr. Sabin.

Corrosion means, in this case, some sort of chemical action. Perhaps oxidation is the most common, but it is by no means the only kind. It is well known that chemical action is always accompanied by electrical action, and it is commonly said that electricity is thereby generated. It would be more accurate to say that chemical action is due to unbalanced attractions among the various kinds of atoms or molecules which are in juxtaposition, and the rearrangement of atoms which takes place is accompanied and in many cases caused by a change in the electrical state of the material involved. It is more accurate to say that the chemical attraction between atoms of different substances seems to be correlated to their thermal and electrical conditions, and anything which changes any of these is very likely to change all of them. So it may be that any electrical disturbance will cause corrosion in certain circumstances, though it may not do so in certain other cases. When the great amount of energy is considered which is constantly being developed in the form of electricity, and when it is considered that nearly all is produced by the combustion of coal, and that nearly all this energy can be reconverted, either by purpose or accident, into chemical action again; when the enormous amount of chemical effect is considered which may in the aggregate be caused by even an exceedingly small percentage of the electricity constantly being generated, and the obvious improbability of preventing considerable leakage, it is clear that those having in charge such property as is likely to be damaged by corrosion have a great deal more responsibility now than formerly.

Mr. Sabin. The writer believes that the rusting of iron pipes or other surfaces is promoted by electrical activity in two ways: *First*, and probably most important, by keeping the pipe charged with electricity all the time, thus accelerating the process which would otherwise be very slow, and might in some cases entirely cease by the formation of a protecting coat of some kind, which, however, ceases to protect when the metal is in a state of electrical tension. *Second*, by the passage of a considerable current of electricity by a definite path between the water pipe and some other conductor, the latter being possibly a trolley-car track, or a gas or water pipe having some other electrical connection, or the steel framework of a building or other structure. In this case the corrosion would be more rapid and local; in the former, more insidious and widespread. There is no doubt that heavy cast-iron water pipes which have laid in the ground long without showing signs of corrosion, have from this cause rusted entirely through in many cases, and become worthless.

The writer does not believe that it is right to hold that there is a new kind of corrosion, needing radically different methods for its prevention; but rather that the need for protection against rust is in general greater than before, and that such protection should be more perfect and more stable and lasting than has heretofore been used. Such improvement must be made in two ways—by using the most suitable material, and by applying it in the best manner. The materials which are in use for this purpose are: Oil paints, which consist of various pigments ground or mixed with linseed oil or some substitute therefor; coal tar; asphalt, or mixtures in which asphalt is the characteristic ingredient.

Competent and disinterested persons differ widely in their opinions on these subjects, and tests cannot be compared unless they are made under closely similar conditions. The writer claims only to give an opinion based on considerable practical and some theoretical knowledge of the subject, but does not assume to be infallible; and the following discussion of the merits and demerits of the principal substances used for coating iron leads to a consideration of what is believed to be a practical advance in the art, as well as one which is defensible on a theoretical basis.

Oil paints consist of a pigment of some sort ground in linseed oil or some substitute. The value of the paint depends on the kind of pigment used, and the proportion and character of the oil. The most common of all pigments used for this purpose is oxide of iron, more or less pure. There are three well-defined oxides of iron which occur in quantity in Nature and may be produced artificially, and most oxides consist of mixtures of two or more of these. The magnetic oxide is usually, and perhaps always, black in color, and consists of three equivalents of iron and four of oxygen. This, on account of its

color, is not commonly a principal ingredient. The anhydrous sesqui- Mr. Sabin.
oxide contains two equivalents of iron to three of oxygen; this varies in color from a rather bright red to dark brown or even purple. The common shades are reddish brown. The natural mineral of this composition is known as red hematite, and it is one of the most common ores of iron. The hydrated sesquioxide of iron, known, when a mineral, as brown hematite or limonite, has commonly two or three molecules of water compounded with each molecule of the oxide of iron. This is also the most common form of rust; but iron rust may also contain carbonic acid, making carbonate of iron and some other compounds. Indeed, the number of compounds of iron which may be present in iron rust is legion. Limonite is said to be always a result of the alteration of other ores, such as pyrite, hornblende, etc., through exposure to moisture, air, and carbonic and organic acids, whence it often contains sulphur and phosphorus compounds and organic acids as impurities.

It should therefore be obvious that it is not enough to say that a pigment is oxide of iron. As a matter of fact, the iron oxide used for paint is usually either a mixture of iron oxide with 30 to 70% of clay or other earthy material of complex and usually unknown composition, which easily falls to a fine powder when dry, and is thus cheaply prepared for use; or it is a granular ore, which may be ground to a powder without much difficulty. Iron oxides have to be sold at a low rate and must be made of such materials as can be ground at a reasonable price. These soft and porous ores are the most likely to be impure, both as to admixture of earthy matter and complexity of the iron compounds. These soft and friable ores invariably, so far as the writer knows, contain some hydrated oxide, which is identical with the principal constituent of iron rust. Probably the proposition can be maintained that it is not good policy to cover an iron structure with iron rust as a method of preserving it from rusting, though the same objections might not lie against its application to a wood surface. The hydrated oxide is not the dominant constituent in any of these paints, but little particles of it are scattered through it, and all that is known of the behavior of paints leads to the belief that these softer particles will tend to gather together in little soft, muddy lumps in the mixed paint, and thus will form centers of rusting on the surface to which it is applied.

But some of the iron oxides are made from an ore containing carbonate or some other easily decomposed salt of iron, by a process of roasting. The writer had experience, some years ago, in running one of these roasting plants, and knows something about it practically. In theory, all the iron should be reduced to a uniform state of oxidation; and when it is ground and put into barrels the samples do appear to be tolerably uniform. But an examination of the ore as it comes out

Mr. Sabin. of the roasting apparatus shows numerous particles, especially in the interior of lumps, which are different in color and in composition from the rest; and the writer has never seen a batch without some portions which were but partially decomposed. It is customary to pick out the worst of these and reject them, but it is impossible to do this thoroughly and it is impracticable to do much of it, as it would increase the expense. The presence of these hydrated lumps is due partly to unequal heating and partly to the presence of some iron compounds which are decomposed only with considerable difficulty. Mixed frequently with the iron ore is enough clay to make 40 to 70% of the resulting pigment, and this is an advantage to the paint grinder, as it makes his pigment lighter and tends to keep it from settling.

The writer is disposed to think that it is the presence of these little bits of hydrate which form the well-known and practically universal rust centers found under iron oxide paints. But it would be a mistake to suppose that sesquioxide of iron itself is as unchangeable as silica, for instance. It is said in Watt's "Dictionary of Chemistry" that "even at ordinary temperatures it frequently acts as an oxidizing agent in contact with organic matter, and is thereby reduced to magnetic oxide, or even to ferrous oxide, and then, by taking up carbonic acid, converted into spathic iron; the reduced oxide, if in contact with moisture, is frequently also reconverted into ferric hydrate by atmospheric oxidation. The oxide is also sometimes further reduced by the action of sulphydric acid, and converted into pyrites." Any such action as indicated above would tend to injure the oil, and make the paint brittle and incline it to crack, and in extreme cases to peel. A very large amount of artificial oxides of iron is sold in this country. These are made from copperas and various by-products, and are usually mixed with lime to neutralize any free acid which may be present; they contain frequently an excess of sulphate of lime and other things as adulterants. These pigments are usually bright in color, as bright colors sell for more; but the brighter they are, the more hydrates they contain. The hydrates of iron contain, roughly speaking, from 10 to 14% of combined water, which is in a rather loose state of combination. Such compounds, which pass from one state of oxidation to another, act as carriers of oxygen, which is the commonly received explanation of the progressive action of rust.

The chemical problems involved in the use of paints having white or red lead as pigments are very obscure. It is well known that lead oxides (and white lead, which is a mixture of carbonate and hydrate, probably behaves somewhat as an oxide) combine with oil to form soaps, which are salts in which the acid of the oil unites with the lead of the oxide. The addition of lead compounds to oil increases its rate of drying whether heat be used to combine them or not; but the amount of lead in boiled oil is only from about 1 to 5% as a rule, and

it is heated strongly with the oil. Such oil is much less durable than raw oil without driers. The amount of lead required to fully decompose the oil is about 40%; but in making red lead paint ten times this amount is used. No investigation of the results of this practice has come to the writer's notice, but a few observations may be in order. Mr. Sabin.

First, the paint is red. This is proof to the writer that a large amount of the red lead is present as a pigment, and it is known to be charged to a very high degree with oxygen.

Second, the paint dries almost immediately. Hence some of the lead combines with the oil, none of which dries by the usual gradual process, and it seems almost certain that the "binder" in this paint is a lead soap instead of the usual linoxyn film. It is characteristic of red lead that when mixed with linseed oil it "sets" into a compact mass in a comparatively short time, which is a practical difficulty in its application. Some of the ways to avoid this will be mentioned later.

This leads back to the fundamental question: Is this lead soap a better binder than ordinary oxidized oil? From all that is known of the behavior of oil to which comparatively small quantities of lead have been added, it seems highly improbable; still it is a practical and not a theoretical question. As regards the use of white lead, there is less dispute. This pigment has long been the standard white on account of its fine color, its great opacity or "body," and the ease with which it is applied. But when exposed to the weather, all agree that it lacks permanence. The oil is converted into a crumbling soap, and the pigment washes or brushes off. As painters say, it "chalks." It is probably the most perishable paint used by house painters.

Carbon in some form, usually as graphite, is used to some extent as a pigment for anti-rust paints. There are two objections to the use of graphite for this purpose, one of which is that as it is the lightest natural substance in use as a pigment, it is not possible to get a considerable percentage of it into oil. And second, it is a flaky and greasy substance, which cannot be ground fine economically, and it settles out of the oil very badly. A purely sentimental objection to it, which is only a cause for suspicion, is that it owes its introduction almost wholly to the efforts of manufacturers of graphite pencils and similar goods, not interested in the paint business at all, to get rid of a lot of their waste product. On the other hand, graphite itself is a very permanent and neutral substance, and some who have used it report very favorably, while others do not. If it is valuable it is an exception to the almost universal rule that the pigment in a paint is more valuable the more finely it is ground and the larger it is in quantity. Oil dries by a process of oxidation, and this leaves the film full of minute pores, and one of the offices of the pigment is to fill up these pores, and thus render the film more continuous. The finer it is, the better it will do this. Also, the pigment increases the "body" of the mixture, so that it is

Mr. Sabin. possible to apply a much thicker film. In this way it acts as a spongy substance, and the finer it is, the better. It serves to make the resulting dry film harder than oil alone would be, exactly as a pavement composed of 80% sand and limestone with 20% asphalt is more durable than one of asphalt alone. These are the principal ways in which a pigment is useful in a paint; and in all these respects graphite is unsuitable. Linseed oil alone affords considerable protection, and it is possible that where good results have been had from graphitic paint a film of oil would have been equally efficient.

Perhaps even more important than the nature of the pigment is the quality of the oil used. The best quality of linseed oil is obtained from pure seed by pressure at a not very high temperature. The oil thus obtained is mixed with some watery juice and mucilaginous and other vegetable matters, from which it separates by standing, and it is then filtered off into tanks where it is kept in warm storage for from one to three months, or sometimes longer. It is found that a considerable sediment settles out, leaving the oil bright and clear and free from moisture. It does not require much capital to build an oil mill, and if the oil can be sold as soon as pressed it does not take much capital to run the business, for oil is sold usually for cash or on very short time. But if it is kept in storage for two or three months it takes considerable capital. One Brooklyn company has storage for 3 000 000 galls. The natural result is that a great deal of oil is sold without proper curing, and after the pigment is put into it, it is hard to find out what is the matter. Further, a great deal of the seed contains a mixture of foreign seeds, such as wild mustard and other weeds, in such quantity that cattle will not eat the oil-cake. And while the adulteration is unintentional, and the oil is commercially called pure, it is very inferior to really pure oil. There is a steady demand for really pure seed by oil-makers for the varnish trade, who get a good price for their oil, and the result is that all impure seed goes into the manufacture of such oil as is sold on price alone. Consequently the makers of high-grade paints have to pay more than the bottom price for oil, and high-grade paints are practically never put on structural iron work, because the consumer will not pay for them, When the purchaser buys a "pure" pigment, ground in commercially "pure" oil, he naturally thinks he has received the best possible goods. But his belief is not commonly founded on knowledge.

There are many large users of paint, such as the railroad companies, who buy their pigments and oil separately and mix them. Such concerns often use boiled oil. Boiled oil does not mean anything definite. The old practice was to put linseed oil in a kettle and heat it to a temperature of 400° or 500°, at which it was said to boil. Linseed oil never boils, however; when it becomes hot enough it is decomposed by the heat and bubbles of permanent gas come off. The heat in the

old practice was only sufficient to attack the foreign vegetable matters in the oil, and at that point some lead and manganese compounds—usually oxides—were added, and these combined with the oil, making it darker in color, heavier in body, and much more active in drying. There was a great difference in these prepared oils, depending chiefly on the amount of metallic oxides used and the amount of cooking. But all such oils are inferior in durability to pure raw oil, for every bit of drier added to oil lessens its permanence. It is supposed that these oxides act as carriers of oxygen, enabling the oxygen of the air to combine with the oil; and their injurious effect is due to their enabling the oxygen to continue its action on the oil after the latter has absorbed the normal amount. So that the best boiled oil is less valuable than the raw oil from which it was made. Boiled oil is now commonly made by adding a few gallons of a liquid japan drier to every barrel of raw oil, which is then said, in factory parlance, to be "boiled through the bung hole." This is really to be classed as an adulteration, for such oil is commonly said to be worse than that which has been treated in the kettle. Of course, the painter prefers it, because the paint dries more rapidly, and that is the reason it is used. But another objection to its use is that it is very difficult, and in many cases impossible, to detect adulterations. One of the commonest of these is to mix in about 30 to 50% of fish oil which has been also treated liberally with driers; and another and still more common mode of adulteration is to add a mixture of mineral oil, rosin and driers, equal in amount to a third or half of the whole, and the writer has no doubt but that some mixed paints are sold which have no linseed oil whatever in them. One of the largest paint concerns in this country makes ready mixed red lead paint under a patented process by substituting a considerable amount of glycerine for part of the oil. Another manufacturer puts in 1 lb. of white zinc to 3 lbs. of red lead, and one of the largest bridges in the world was painted with "pure red lead" paint in which the pigment consisted of 2 lbs. of whiting to 1 lb. of red lead. The writer also knows of a government contract for a very large amount of pure white lead which went to a contractor who supplied a paint in which the pigment consisted of 100 lbs. of white lead to 1 000 lbs. of barytes, and there is a well-known brand of non-magnetic iron oxide which is said to contain 72% of iron when the theoretical maximum is 70%, and, as a matter of fact, the pigment in question contains not over 25 per cent. A letter to one of the largest contractors in New York was recently shown the writer, offering pure oxide mixed paint for 45 cents per gallon, when ordinary oil was worth 56 cents, and it is often said that oxide paints can be made at a cost of 45 cents to 55 cents per gallon. The writer has some practical knowledge of the cost of paint grinding, and he has lately gone over this matter with the superintendent of one of the largest and

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Mr. Sabin. best paint factories in the country, trying to get at the absolute minimum cost of such a paint. In the first place, a gallon of paint contains about 6¼ lbs. of oxide, worth, say, 9½ cents, and 6¼ lbs. of oil, which, at 56 cents per gallon, is worth about 46½ cents, making 56 cents for material. Now, if it is mixed in a paint mixer, not ground through a mill as it ought to be, but as it is not usually, and is made in large quantities, the cost of labor and power may be figured down to, perhaps, 1½ cents per gallon, without allowing anything for supervision; ½ cent per gallon must be added for wear and tear; it costs at least 2 cents per gallon for barrels, and 1½ cents to deliver it F. O. B. in New York, making in all 5 cents per gallon. If to this is made an allowance for superintendence, rent, insurance and interest on capital invested, at least 5 cents more must be added, making the actual cost under the most favorable circumstances 66 cents per gallon. If it is to be put through a mill, the cost of labor and power will be not less than 2 cents per gallon additional, with another addition for superintendence, etc., which would bring the cost up to 70 cents. But in any manufacturing business there is more or less loss of material and of time, and there must be also some little profit; and it was the opinion of the expert that any man who attempted to sell a perfectly straight well-made oxide at 75 cents per gallon would lose money. In the factory where he is superintendent it is necessary to grind certain cheap paints and deliver them, without packages, to another department of the same factory; and it is customary to charge the second department 1 cent per pound for grinding, which, in this case, would be 12½ cents per gallon, which is the estimated actual cost; this substantially agrees with the figures given. A large manufacturer in Canada, where labor is cheaper than here, contracted to have his liquid paints ground and put into the packages which he furnished for 2 cents per pound for labor only, which would be 25 cents per gallon on oxide paints; this was cheaper than he could do it himself and proved to be too little to remunerate the contractor.

The cost of a gallon of pure red lead paint, very hastily and imperfectly mixed (as it must be) just before using, cannot be less than $1 50 per gallon, and probably is a good deal more than that. The exact cost cannot be computed without knowing the amount of pigment used, in regard to which practice is variable; but 20 lbs. per gallon makes a very thin paint. The cost may run up to $2 per gallon. This question of cost of paint is of more importance than it might seem at first sight, for it is evident that a very cheap paint is not what it is pretended to be, and, if so, doubt is at once thrown on its whole value. As a general rule, no really first-class goods can be made without skilled labor, and the more skilled labor used, the greater will be the cost. A thing is not good merely because it is expensive; but if it is a thing which is capable of being made better by skill, then the best

of the sort cannot be cheap, and is yet likely to be most economical in use. When paint is offered at 45 cents per gallon the price is against it, and it is easy to make a paint which is honestly worth, from the manufacturer's standpoint, $1 50 per gallon. Indeed, there are enamel paints which are ground in varnish which are worth from $8 to $12 per gallon, and cannot be honestly made and sold for less. It is worthy of notice that the practice is almost universal of thinning oil paint with turpentine or benzine. This is an adulteration, whether intentionally so or not. Often it is done to make the paint spread more freely, but the result in all cases is to make a thinner film of dry paint, and when a pigment of great body is used, as is commonly the case, an exceedingly thin film will cover up the iron. From this point of view a less opaque paint would be better, as it would then be impossible for the painter to apply so little. A good heavy coat of oil paint is better than an excessively thin one, and if a manufacturer claims that a gallon of paint will cover 600 to 800 sq. ft., he is advising the use of a coating of not much more than a half to two-thirds the proper thickness. A gallon of any paint will cover that surface if it is made thin enough. Mr. Sabin.

Coal tar is the next preserving agent to be considered. The most important fact in regard to coal tar is contained in these words, taken from Ure's "Dictionary of Arts," and written more than 40 years ago: "Factitious tar and pitch, being generated by the force of fire, seem to have a propensity to decompose by the joint agency of water and air, whereas mineral pitch has been known to remain for ages without alteration." In the first place, coal tar is a product of distillation, and, with the exception of a considerable amount of soot, it has been condensed from a state of vapor; the inference is that it can be converted into vapor again, leaving the uncombined carbon behind. Next, it is to be considered that tar from different works differs widely in physical and chemical characters. The standard books on chemistry give lists of at least 100 different compounds contained in coal tar, and there is one chemical factory in Germany where more than 100 products are made from it; there is an uncounted myriad of things made from it by more elaborate processes, including analine and azo dyestuffs, carbolic and many other acids, and a large proportion of the most complex chemical substances known. By making it from different kinds of coal, or different mixtures of coal, or by using different degrees of heat in the gas retorts or in the condensers, products are obtained which are all called and sold as coal-tar, yet differ widely in every way, except that they are all black, and sticky, and cheap. The manufacturer of secondary products has to take great care to buy exactly the kind he can get his particular class of products from; but to the engineer it is all alike coal-tar, and all equally useful to apply to his iron-work. The writer has seen certain kinds of it, thinned with

Mr. Sabin. benzine, sold at 16 cents per gallon for a smokestack varnish, and the purchaser thought himself abused because it was not durable. Simplicity and durability are very closely connected, and there is nothing known to man that compares for a moment in complexity with any of the unsavory messes called coal-tar. The primary reason for using it is that it costs practically nothing. It is easily applied, it is adhesive, it is not possible to dissolve all of it off with water, and it usually preserves the pipes (for it is used almost exclusively on pipes) from rusting until they are out of sight in the ground. Probably every one has seen many pipes dug up from which all signs of it have been removed, but often there is enough soot and other insoluble matter to show a black film after many years. In some cases, from some peculiar and accidental composition of the coal-tar which chanced to be used, this residuary film may have had some protecting action; but a majority of cases are like one described by Mr. Birdsall, Chief Engineer of the New York City Department of Public Works. A pipe which had been down 18 years was taken up, and was in a fair state of preservation, and the coal-tar film was also nearly intact, but there was an appreciable space between the black film and the surface of the pipe. The metal in such cases is preserved simply because there happens to be nothing present sufficiently active to corrode the cast-iron, and also because there is so much iron there.

The original process for treating water pipe which was recommended by Dr. Angus Smith, specified that a considerable amount of linseed oil should be mixed with the tar; this no doubt improved it somewhat, but the writer cannot learn that it is ever used at present, and doubts if it ever was of much value. Attempts have been made to substitute coal-tar for asphalt in pavements, but the tar has invariably proved worthless, being subject to rapid and certain deterioration, though it always remains black, as it does on water pipes. It is also compounded with dead-oil, rosin, benzine and other things to make a paint which is miscalled asphalt paint, but has absolutely no asphalt in it. It is a great abuse of asphalt to confound it with coal-tar. Asphalt is a mineral, or rather a class of minerals, intermediate between the petroleum oils, from which many geologists think it is derived, and bituminous coal, and seeming to shade off gradually into both. Dana says, in his "System of Mineralogy," that "petroleum passes by insensible gradations into pit-asphalt or maltha; and the latter as insensibly into asphalt or solid bitumen. The fluid kinds change into the solid by the loss of a vaporizable portion on exposure, and also by a process of oxidation, which consists first in a loss of hydrogen, and finally in the oxygenation of a portion of the mass." Maltha is an old Greek name first applied to the more fluid and tar-like bitumen by Pliny, and is still used with that meaning; and the substances known by this name are closely related to the naphtha oils, from which they

differ in having greater viscidity, deeper color, and higher specific gravity and atomic weight. They are said by Dana to enter into the constitution of all free-flowing petroleums, but are especially characteristic of the denser kinds and viscid bitumens, and exist also in many asphalts. Some of them are separated from petroleum in the ordinary process of distillation as a residue left in the retort; the California maltha is of this character, and is not to be confounded with coal-tar or coal-tar pitch, which it resembles in appearance. These artificially prepared bitumens are soft, and differ in important respects from the natural hard asphalts. Chemists and mineralogists formerly had a theory that asphalts in general were mixtures of two substances, one an oily compound, called petrolene, and the other a fusible solid called asphaltene; and that they differed only in the proportions of these two ingredients. This view is still held as substantially correct, except that there are several of the softer or more oily constituents instead of one, and also probably several of the harder components differing chiefly in degree of oxidation. The harder asphalts exist in large masses, that at Trinidad being of great depth, and the veins of gilsonite being several feet in thickness and imbedded in the earth; it is therefore protected from atmospheric agencies except superficially, and the superficial portions are of less value than the rest. The way in which it has reached its present constitution is unknown, and so is its origin. All that is known with certainty is that some kinds of asphalts are suited for certain purposes and others are not; and knowing their composition, a theory can be advanced to explain the facts, but it must be remembered that the facts are surer than the theory, and that should the theory be successfully attacked, the facts would remain the same. Briefly, then, the theory proposed is that the toughness of asphalt is largely due to its more fluid constituents, and that when spread out in a film, as a paint, it loses these by evaporation or otherwise, and becomes friable and crumbly, and easily falls to a powder. This may be tested by dissolving any asphalt in turpentine or bisulphide of carbon to a thin liquid and painting it out as a thin film on a piece of metal which is exposed to the weather. In a few days, or weeks at the most, it can all be rubbed off as a brown powder. It is natural to expect that the hard asphalts would reach this condition first, and this might lead to the conclusion that the softer kinds would be the most valuable; but the opposite conclusion is the true one, as will be shown; for if the asphalt coating goes to pieces, as it evidently does, from the loss of its softening and toughening ingredient, the obvious remedy is to replace the latter with some elastic matter of greater permanence; and such a constituent is found in linseed oil, which when oxidized becomes a tough substance of the very greatest durability. A hard asphalt can be combined with a maximum quantity of oil, while to a soft one, which is charged

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Mr. Sabin. with a portion of perishable oily matter, it is possible to add but little of the more permanent elastic constituent, and the compound thus made will undergo a rapid change upon exposure, which is not the case with the other, which quickly comes to a permanent condition by a process of oxidation like any other well-made paint or varnish.

This leads to the consideration of solutions of asphalt and other bitumen in turpentine, benzine and other solvents, used as a varnish. Many of these preparations contain rosin, which is added to improve their appearance and also makes them cheaper, but is detrimental in every other way. Some of these are true oil varnishes, in which the asphalt acts as a sort of mineral resin and frequently is compounded with fossil resins and properly combined with linseed oil, and these are very durable; but a solution of any of the bitumens alone in a solvent is certain to undergo decomposition by the evaporation of the solvent when exposed in a thin film to the weather. In these cases greater comparative durability is reached by employing a soft bitumen, such as maltha or pit-asphalt, because the very heavy mineral oil in it is removed somewhat slowly; if the coating is very thick some of it remains for a considerable time, but its disintegration is steady and certain.

The practice of using considerable quantities of benzine or bisulphide of carbon in these mixtures, aside from its fire risk and other objectionable qualities, is open to the following objection, first pointed out by Mr. M. P. Wood. The rapid evaporation of the solvent during the application of the coating lowers the temperature of the metal and consequently of the adjacent surface, and if at the time the atmosphere is nearly saturated with moisture the metal will be cooled below the dew point and a thin invisible film of dew will be deposited on the surface which is then quickly covered with the paint, thus preventing perfect adhesion and supplying a favorable condition for corrosion. This seems to the writer a very serious matter, and may explain the fact that in some cases the use of such preparations has been much more unsatisfactory than in others. This may be one cause of the well-known inferiority of benzine to turpentine as a vehicle in varnishes; the latter may be put into the varnish at a high temperature, and unites with it more than benzine does, besides which it has both a higher boiling point and much less diffusive power, and it evaporates very slowly. On account of its low boiling point and high diffusive power, carbon bisulphide is worse in this respect than benzine, besides which more than four-fifths of it is sulphur, making it one of the most powerful sulphurizing agents known, and it is for that purpose it is chiefly used.

It has long been known to varnish-makers that the fossil resins known as copals, such as the New Zealand Kauri, when added to asphalt varnishes improve their durability. This is probably partly

owing to the fact that such compounds are of greater density, as the resin dissolved in the oil and asphalt tends to make it a more compact substance, and partly because it increases its electrical insulating power, and also in considerable measure because such a resin is very indifferent to the action of sulphur gases. For all these reasons it seems to the writer that the maximum of durability is only to be reached by a compound of hard asphaltum, copal gum and linseed oil, thinned, if necessary, with pure turpentine. It is of the highest importance that the oil employed should be pure, and also that it should be so refined as to have its non-drying constituents removed, so as to avoid as much as possible the use of driers. This is of more importance than in a pigment and oil paint, because the most obvious thing about asphalt is mentioned in the observation of M. Riffault, made some 30 or 40 years ago, that "asphalt destroys the drying quality of oil." This is due to the fact that, being a viscous substance, it closes the pores of the oil and thus obstructs the entrance of air and moisture, which is again the cause of the great durability of such compounds. Mr. Sabin.

Not only is it necessary to have the most suitable materials in such proportions as experience has shown to be best, but the ingredients should be compounded in the most approved manner. Long experience has shown that there are certain temperature curves to be followed in combining certain materials, differing for different compounds, a departure from which injures the durability of the resultant compound. The upper parts of these curves approach dangerously near to the decomposing point of the oil, and as it has been found that a suitably refined pure oil has this point more than 100° Fahr. higher than common oil, it is on this account also important to use the highest skill in the manufacture. The choice of ingredients is of less importance than their proper proportion, and this again is of no more value than the use of the best process of combination.

The best coating for iron work should have a kind of toughness which does not depend on a perishable ingredient, and is, therefore, not rapidly affected by age; its elasticity should not be lessened by cold; it should not soften but rather harden by heat; it should contain no solvent except turpentine, which experience has shown to be neither disagreeable nor dangerous in its usual application; and it should contain nothing which will have a corrosive action on the iron, nor act as a go-between to carry oxygen from the air to the metal. It ought to last forever, but nothing has yet been discovered which fulfills this condition, although it is now possible to make compounds of great permanence. It ought also to act as an insulator. These conditions are well satisfied by a compound such as has been described.

It has long been the custom to apply the coating material as a liquid at ordinary temperatures with a brush to the surface, more or

Mr. Sabin. less clean, of the metal. It is justly regarded as important that the surface should be clean, for the reason that incipient rust spots eat into the iron by acting as carriers of oxygen from the air. This assumes that the air can penetrate through the paint, which is generally true. It is plain that if the paint were absolutely impervious this process could not go on, and as it is practically impossible in most instances to have the surface absolutely clean, it is of importance to have the coating as continuous as possible. It is further desirable to have a paint which, if applied with a brush, will dry with sufficient slowness to flow freely and not set, and yet will dry soon enough to be safely applied in ordinary seasons, whether cold or warm weather. In view of the fact that all these coatings are somewhat porous, it is desirable to apply at least two coats, allowing plenty of time for the first to harden, so that the second coat may fill up the pores in the first.

For some work, especially for water pipes, there is a much better way of applying the material, namely, by dipping the pipe or other object in a vat of the coating compound and then putting it into an oven and baking it. This process, known as japanning, has long been applied to small articles, such as door locks and latches, metal sign plates and small pieces of machinery, such as sewing-machines; and when good material was used in the right manner it gave a high degree of durability, the coating usually outlasting the usefulness of the article which it protected. This is because the coating is kept in a fused or plastic condition, and is protected from the weather during its entire period of oxidation. This condition promotes its intimate and continuous contact with the surface of the metal, and an entire absence of porosity. It is found also that such a coating acquires hardness without losing toughness, and, as it has a very smooth surface, it resists abrasion to a remarkable degree. This process of baking is capable of very wide application. If a surface of metal or wood is coated with an ordinary varnish of good quality and is baked, even though the temperature may not exceed 200° or 225° Fahr., its durability is enormously greater than if dried in the ordinary manner, and this process is now applied in the use of varnish on woodwork by some of the piano makers. There can be no doubt that a properly made baked coating greatly excels in durability any coating not so treated. It is reasonable to expect, and it has been empirically proved, that a compound which requires a high temperature to harden it is the most durable, for the change induced by the heat is not one of evaporation, but is a chemical one, and if the compound yields only to high heat it is an indication that it strongly resists all influences tending to produce chemical change.

The application of this process to very large work involved some important changes in the process and materials of manufacture, but

the difficulties were successfully overcome, and about 14 miles of 38-in. riveted steel pipe was satisfactorily coated for the city of Rochester. The evident value of this coating led to its subsequent adoption by the city of Cambridge, Mass., where about 4½ miles of 40-in. steel pipe is now being made and coated; and the same coating has been adopted by the authorities of Allegheny, Pa., for 50 000 ft. of 5-ft. pipe. It is also likely to be used for other large work in the near future. The Allegheny work is not yet actually under way, although it will be very soon; but the Cambridge work is being done by Edward Kendall & Sons of Cambridgeport, the plant consisting of a vertical cylindrical steel tank, steam heated, for holding the liquid, this tank being about 33 ft. in depth and a little over 4 ft. in diameter. Adjacent to this is the oven, about 12 x 20 ft. on the ground, 33 ft. high, with openings in the top for eight pipe sections, the openings being covered with removable lids. The pipes are first put into the oven a few minutes to warm, then lifted out and dipped, replaced in the oven and baked for two or three hours at a temperature of 450 to 500° Fahr., this temperature having been found suitable for the proper hardening of the compound used. If for any reason so high a heat is objectionable on any special work, the coating compound could be modified so as to conform to the conditions indicated. Mr. Sabin.

The oven is of brick, with an iron roof covered with cement and gravel, and the lids covering the holes are of light steel backed with asbestos and wood. The oven is heated with four fuel-oil burners, and the products of combustion escape into the open chamber of the oven, thus utilizing the heat fully. There is no danger of fire. It is necessary to have so many burners only to be able to get up the heat quickly; comparatively little fuel is required after the oven is hot. The process is simple and gives uniform results, but needs constant and intelligent supervision, particularly for securing uniformity of heat. The pipe sections are 28 ft. long, made of three sheets of $\frac{5}{16}$-in. steel plate; and after placing in the trench they are field-riveted together. The rivet heads and some of the surfaces of these field points are then painted with a sort of varnish made expressly for the purpose, containing the same ingredients as the baked coating, but thinned with turpentine so that it may be easily applied with a brush. While this is probably not quite so durable as the baked coating, it has been so satisfactory that it is now used largely for painting bridges and structural steel work of buildings. It has been suggested by William Jackson, M. Am. Soc. C. E., that the pipe sections might be made with pressed steel flanges and put together with suitable packings, so as to avoid the use of any but the baked coating.

Extracts from a letter dated April 25th, 1895, from E. Kuichling, M. Am. Soc. C. E., are appended, which give the result of tests made by him during the past two years.

Mr. Sabin. "In relation to the experiments which I made with your japan coating, and also with a number of asphaltic paints. The first samples which you sent me (small sections of 1-in. cast-iron pipe), were subjected to tests by immersion in moderately alkaline and acid water. I cannot describe the strength of these solutions exactly, but will give them in popular language. About ½ oz. of caustic soda was put into 1 quart of water to form the alkaline mixture, and about the same amount of hydrochloric acid in 1 quart of water to form the acid mixture. A sample was placed in each of these solutions in fruit jars and kept therein for about one month. No change in the quality of the coating could be detected at the end of this time. The two samples were then buried about 3 ins. below the surface of a richly manured garden soil, and were allowed to remain therein about one year, during which time they were frequently dug up and examined. No sign of deterioration or rust appeared. It was, however, necessary to reach some decision about using the coating earlier, and during the first month of the burial of the two samples, the ground was regularly watered every day with both fresh water and small additions of ammonia in water to stimulate the growth of the ground bacteria, with a view to ascertaining whether such organisms would have any action upon the coating. This was done in the summer time when the conditions were most favorable for the growth of such organisms. No change in the coating, however, could be detected, even with the aid of a powerful magnifying glass. For the remainder of the season (1893) the same treatment of watering was kept up, but not with the same regularity as before, and during the winter and following spring the samples were left undisturbed in the ground. They were again exhumed for examination early in June, 1894, and the coating was still found to be intact, although the gloss seemed to have been slightly reduced. They were then replaced in the soil and examined the following October, but no perceptible change had taken place. With the expectation of subjecting them to a severer test, the two samples were then set vertically in the ground with their tops projecting somewhat, and remained so until March, 1895, when they were examined casually and found to be still in excellent condition. On looking for them early in April, however, they could not be found, and were, doubtless, removed by the gardener, and thus lost.

"Almost identically the same experience was had with two samples of 2-in. pipe coated in August or September, 1893, at the Rochester Bridge and Iron Works, by your process, the coating in this case also remaining practically unchanged during the entire period up to April, 1895. We have thus a record of nearly two years' usage under worse conditions than probably occur in the subsoil where a large pipe is buried.

"Another experiment consisted in placing a sample of coated pipe in a jar of water and leaving it therein for two months, renewing the water occasionally; and still another experiment was in suspending a sample of coated pipe in the air on the roof of the building in which my office is located, in such manner that it was fully exposed to the weather, and frequently also to the smoke and fumes from the chimney of the building. No change in the coating appeared in this sample after six months' exposure, when it was finally blown from its fastenings during a hurricane, but was recovered after having broken through the skylight of the adjacent building.

"While these experiments were in progress early in 1893, similar ones were made with a variety of asphaltic paints or varnishes, ap-

plied with a brush, like paint, to small pieces of thin sheet iron. None of these experiments were satisfactory, especially those in which the samples were exposed to the air, as above described, or where they were buried in the ground. A few weeks usually sufficed to produce extensive rusting and a marked deterioration of the coating material itself. Mr. Sabin.

"I regret greatly that I have not yet been able to obtain from Mr. Alden the record of the experiments which he made independently with similar samples of pipe coated by your process, in the fall of 1893. I can, however, say that he subjected such samples to the following tests: 1. A solution of caustic soda, of moderate strength. 2. A solution of common salt, somewhat stronger than sea water. 3. The action of stagnant water, the sample being placed in a fruit jar and left so for weeks. 4. The action of running water, the sample being suspended under the faucet of a wash basin or sink. 5. The action of ammonia and organic salts, by placing a sample in the urinal of his office building containing about eight occupants. 6. The action of sulphur fumes from ordinary bituminous coal, by suspending a sample over the forge used for making or heating rivets. 7. Burial in the ground where hot water and oil condensed from the exhaust of a steam engine would drip to considerable extent. All of these samples were left in place for more than three months without showing any rust or appreciable deterioration of the coating in any respect.

"Previous to the experiments above set forth, I also made some with coal-tar pitch and mixtures of Trinidad asphalt with coal-tar pitch, having been led thereto by the manifest deterioration of such coatings on pipe exposed to the air. The great difficulty was to obtain a coating which should be hard, adhesive and still ductive or elastic. A coating mixture which was satisfactory when used in cold weather would become soft and run or flow when exposed to the sun in spring or summer; and, conversely, a mixture which would be adhesive and fairly hard in summer, would become extremely brittle and fly off from the metal in large areas in cold weather. In many cases, too, no proper adhesion to the metal could be secured, so that by hammering the surface lightly, even in warm weather, considerable scaling off would occur.

"I also tried a mixture formed by adding some linseed oil to coal-tar pitch and asphalt, but here, again, lack of adhesion occurred unless the quantity of oil became so large as to render the material sticky when cold. In all these experiments the aim was to secure a coating which would be a liquid when highly heated, and reasonably hard when cold, so as to obtain the result by dipping or immersing the object in the usual manner.

"I also made some experiments by adding quicklime and resin in varying proportions to the above-named materials, but without satisfactory results.

"The above is written mainly from memory, especially with reference to the last-named set of experiments, which were made at intervals during a period of eight or 10 years prior to 1893, and the record of which is lost or destroyed."

A. P. Boller, M. Am. Soc. C. E.—There is probably no branch of the arts that has received less intelligent scientific study than that of paint, largely due, probably, to its having been left so much to the shop and contractor. With them economy is absolutely the ruling consideration, and left to themselves, the cheapest mixture obtainable is Mr. Boller.

Mr. Boller. chosen. Consequently, the aim of the paint manufacturers is to meet the market, and innumerable compounds have been devised to cheapen mixtures.

There will never be any great improvement in paints until engineers and architects take the matter absolutely into their own hands and hold strictly, not only to a specification of quality, but also to the condition of the metal to which it is applied. No matter how good a paint is, it cannot be efficacious unless the metal is in proper condition to receive it. This is a most difficult matter to control, as the shop work is completed, when ready for painting, and the anxiety of the shop to get the work shipped under press of erection requirements or to reach an estimate, leads to a most careless application of the paint. The work is usually painted out of doors, which is not so bad in dry summer weather, but in damp weather or frosty weather no paint can get a proper contact with the iron.

The priming coat is the vital coat, and no reasonable expense should be spared to have the metal perfectly dry, and cleaned as far as practicable from mill scale. Poor success with red lead has weaned the writer from a predilection he once had for that paint. He had to have some girders, after less than a six-months' painting with red lead, scraped and reprimed with other paint. The red lead paint had behaved very badly, the rust having thrown it off in great flakes. He is uncertain as to the condition of the girders when they were primed at the shop. Inasmuch as red lead is often adulterated, he had it carefully analyzed, and it was reported commercially pure and the boiled oil was of the best. Further, red lead beside being expensive, taking about 17 lbs. to the gallon, is the worst kind of paint to get applied. It must be made in very small quantities and kept continually stirred, or it will at once settle and cake. It is almost impossible to put it on without streaking; it is not fluid, will not run into cracks, and will be a thin reddish oil in places, and in others thick and pasty. It is all very well to say that is not the right way to apply it, but the yard men and boys at the shop are crowded to get through, and it adds greatly to inspection expenses to have a specially detailed inspector to stand over it. The author's deductions for the use of boiled oil as a primer are a *non sequitur* from his records, and how he can recommend this in the face of his own comments it is difficult to see. He says :

"Linseed oil, so far as known, is the best liquid within reasonable cost that can be used for paints, and is, in fact, the preserving agent of the paint. It is, however, readily destroyed by weather, and to preserve it a pigment is mixed with it. * * * C. B. Dudley, M. Am. Soc. C. E., found that while linseed oil alone, after being dried, absorbed water rapidly, this absorption decreased the greater the amount of iron oxide present, and practically ceased finally."

If oil-primed metal could be immediately covered with a pigment coating, good results might perhaps follow, but between priming and

such coating the time is entirely too great; the oil is almost immediately attacked by its great enemy, moisture, and destructive oxidation of the oil commences. The extent of rust pitting is only measured by the interval between the coats. When a coat of oil is put on it will run more or less and skin over in places where it collects. This part will not dry hard and will produce a gummy substance which will ruffle up when paint is applied, or when painted over will leave a place under the skin which will remain soft, leading to the pitting mentioned as follows by the author: "Under the scale, more particularly on the eye-bars and heavy angles, it was not uncommon to find oil in almost a liquid condition. The outside of the drum was pitted more or less and showed rust under the paint, although this was generally soaked full of oil." Now, if this condition prevails on a structure erected less than a year, wherein has the oil been of advantage? Mr. Boller.

The author's record shows up much better for the oxide of iron paint as a primer than pure oil, and he demonstrates absolutely the necessity of a pigment for best results. The key to all painting, of course, is to prevent oxidation, and that paint is the best and cheapest which prevents moisture attacking the oil conveyor for the longest time. To accomplish this result, cheap ingredients cannot be used, irrespective of their combining qualities, and they should be combined on a rational basis of experimentation. There are few such paints in the market of which the writer is aware, but there are some that have been intelligently compounded on scientific principles. They are necessarily not cheap paints, but give them a chance on new clean dry metal, and the record will be very different from that listed by the author. If economy in painting is of great importance, let it be exercised upon the finishing coats, but do the priming with the best material attainable. There is not much use in putting expensive paint over cheap priming, for by the time the work is ready for the second coat, rust will have started, and good and bad paint will come off together.

A priming paint has been prepared by Mr. A. H. Taylor, which he manufactures under the name of "Eureka," after several years of careful experiment, which is a combination of certain ingredients with the purest boiled linseed oil treated by a secret process rendering it practically impervious to moisture, which in the writer's opinion is the true direction in which to improve paints. He has seen metal covered with one thin coat of Mr. Taylor's prepared conveyor oil alone, that after four years of continuous exposure to the elements appeared as fresh as the day it was put on, while the adjacent portion purposely left uncoated, was badly rusted and pitted. With pigment added to such a conveyer, as an additional fender against oxygen and to obtain color, such a paint would seem to come very near to an ideal primer.

Mr. Boller. The grinding together of pigment and oil for any paint the writer considers of importance, as the only way to thoroughly commingle the ingredients, although entirely impracticable for red lead compounds. But it should be done with the iron oxide paints if the best results are to be obtained. No paddle mixing can take the place of mechanical grinding.

Mr. Gerber. EMIL GERBER, M. Am. Soc. C. E.—The author's attention has been called to an error in relation to the pigment used by the Chicago and Northwestern Railway. He was informed by the chief engineer of the road that the object of roasting was to drive off sulphur. Mr. Davidson, the chemist and engineer of tests, says, however, that it is to drive off moisture.

The discussion brought out by the paper is exceedingly interesting and much more general than the author had dared to hope. The important point, viz., the necessity of absolutely cleaning the metal, seems to have been generally recognized and all agree with it.

The choice of a pigment is another matter and the difference in opinion is perhaps an honest one. The author has been criticised as being prejudiced in favor of one article, not to put it stronger. He wishes to state, however, that when he began the examination, after having read Mr. M. P. Wood's able papers and others, and knowing the great favor in which red lead was held, he was at least as ready to find good red lead paint as any other and was greatly disappointed when most of that examined proved so unsatisfactory.

Mr. Emery is undoubtedly right in his conclusion that almost any effort to protect metal with paint is of some benefit. The more perfect this effort is, and that in the direction of the manner of application more than in the material, the better will be the result.

Mr. Just calls attention to the fact that rust is in streaks to the height of trucks on the New York Elevated railroads and this shows clearly the necessity of using a tough and adhesive paint. The author noticed similar rust streaks on a bridge on the old Boston and Providence Railroad. The structure spanned a highway and high wagons had evidently rubbed off from the lower flange the red lead which covered the structure well elsewhere, but which was brittle.

It is interesting to compare the covering powers claimed for various paints by different Members. The truth is pretty well brought out by Mr. Sabin and others that the more area a paint covers, the thinner the film is, and hence the less it is able to protect the metal, the question of merely coloring a given surface not being at issue here.

Mr. Montfort and others object to the use of oil as a first coat, because in transportation cinders get into it and the surface is rough forever after. The same objection would hold if good paint were applied just before shipment, and the metal should be cleaned in the field at all events.

Mr. Thomson's suggestion of heating rust to dehydrate it seems to be a good one. Mr. Gerber.

Mr. Robinson has found some things in the paper which are rather curious. How one bridge on which red lead was good out of eight painted with it makes 71% is new mathematics. Perhaps brittle paint that does not adhere well is not objectionable to him. The rails out of the old foundation on the site of the Woman's Temple in Chicago were seen by the author. He believes, however, that the condition was quite as much due to their being incased in cement concrete as anything else, for some iron taken out of the masonry of another building which had stood 20 years was just as clean, but showed no sign of any paint.

Mr. Nichols draws some conclusions with which the author does not agree. That metal in one bridge may be smoother than in another is not strange when a little thought is given to the subject. If for one the metal lies out of doors for some time before being manufactured and gets rusty, while for another it is kept under cover and worked up as fast as received, the difference is produced at once, even if both lots were equally smooth at first. If paint did not prevent a thin film of rust from spreading there would be few structures in existence that could be said to be evenly fairly protected a year after painting. Mr. Nichols evidently infers that the author believes that plates are always less effected than shapes. While he has often found this to be the case and does believe that the chances are in favor of plates, he would by no means wish to convey the idea that it could not well be otherwise, and in the case of at least one structure it is distinctly so mentioned.

That "rust is unknown under red lead paint" is true only for those who have not looked for it carefully. A circular recently issued by a paint manufacturer gives a lithograph of a very bad case of it. A case similar to the one illustrated was found by the author recently at Providence, R. I., on some metal which had been painted with red lead within six months. The paint was intact, but numerous and large rust spots under the paint were plainly indicated by the discoloration of the paint, and on scraping there was no question whatever as to there being rust under paint. Some go so far as to say red lead causes this rust. The author, however, does not hold such a view in regard to lead paints any more than iron paints.

There seems to be a common idea that oxide of iron used for paint pigments and rust are identical. Such is very seldom the case and the difference is pointed out by several members in this discussion. Rust is hydrated oxide of iron, and the pigments are generally anhydrous oxides. It is no more difficult to get good dry anhydrous iron oxide and mix it with pure oil under proper supervision than any other pure paint, and the author does not recommend getting it in any

Mr. Gerber. other way. There are good mixed paints of many kinds, but most mixed paints on the market are bad as well as cheap. One trouble with paints used on railroads is that the purchasing agents usually award the contract for furnishing paint to the lowest bidder.

Mr. Greiner does not believe red lead to be good on iron structures exposed to fumes of combustion, and it is to be regretted that he has not said so and given his reasons for so doing when he is so much in favor of it in other places.

The author fails to follow Mr. Boller in his deductions from the paper. The author does believe paint to be the best primer under ideal conditions, but thinks his recommendation to use linseed oil under existing conditions is perfectly logical.

The author has been particularly interested in Prof. Sabin's discussion, as he believes, with Prof. Dudley and others, that in the direction of carbons or mixtures with carbons a better paint will be found than in either iron oxides or lead compounds. Unfortunately the right kind of a carbon paint is not yet in common use. Furthermore, he believes that rapid drying paints will give way to the slower driers, as there is no doubt that rapid drying is one of the chief causes of brittleness and want of adhesion.

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THE SANTA ANA CANAL.—DISCUSSION AND CORRESPONDENCE ON PAPER No. 743.*

By J. J. R. CROES, WILLIAM BARCLAY PARSONS, L. L. TRIBUS, JAMES DUANE, R. C. GEMMELL, FRANKLIN RIFFLE, CHARLES W. GREENE, JAMES D. SCHUYLER, DAVID C. HENNY, L. J. LE CONTE and WILLIAM HAM. HALL.

DISCUSSION.

Mr. Croes. J. J. R. CROES, M. Am. Soc. C. E.—The work done on the preliminary surveys described in the paper seemed to be so full, so exact and so costly that the advisability of so large an expenditure for the sake of saving, possibly, a few dollars in construction might be questioned. Still the difficulties due to the nature of the country were so great that the speaker did not think such a criticism would be a fair one. He was much impressed with the ingenuity and fertility of resource of the engineers in the design and construction of these works, and commended the care taken by them in keeping such an accurate account of the force employed and the cost of construction of so important a work, and then placing it on record.

* "The Santa Ana Canal of the Bear Valley Irrigation Company," by William Ham. Hall, M. Am. Soc. C. E., *Transactions*, Vol. XXXIII, p. 61.

Mr. Croes. There is a tendency at the present time, not only in the West, but in all parts of the country, to entrust entirely to contractors the details of preliminary surveys and of construction, the engineer of the company having very little to do with them. In this case the company's engineer seems to have had everything in his hands and to have done his work thoroughly. This method of procedure the speaker considered unquestionably more likely to ensure results in both design and workmanship which are to the company's interest than the placing of the whole matter in a contractor's hands.

Mr. Parsons. WILLIAM BARCLAY PARSONS, M. Am. Soc. C. E.—Two years ago the speaker was sent to examine the work described in the paper, at which time about a quarter of it was in course of construction; he was familiar with the details and could testify to the thoroughness of the work done. A large number of wooden stave pipes under considerable pressure which he had seen were all practically tight. The plaster alluded to in the paper was made of imported Portland cement, which is the cheapest cement, all things considered, that there is in southern California, costing from $3 to $4 a barrel. It is brought there in vessels coming to take cargoes of grain to Liverpool, and the freight charges are nominal. He called attention to the exceedingly rough character of the country in this locality, which had an influence on the cost of the preliminary engineering work. There were no previous surveys whatever, and care was necessary in the adjustment of the details of location to avoid loss of water, which is very scarce in this region. In order also that the work might progress rapidly, it was necessary to make an attack at the same time on different portions, and when the several portions met to have them meet in accordance with the plans. The fact that the work did come out as expected seemed to justify the expense of the original surveys.

Mr. Tribus. L. L. TRIBUS, Assoc. M. Am. Soc. C. E.—The author's method of taking the top water from a silt-bearing and variable stream, and of getting rid of the silt is ingenious. A somewhat similar plan was proposed several years ago for a water-works system where the supply was to be drawn from a river which carried a large quantity of earthy matter. A weir about 100 ft. long was designed to take about 2 ins. of water from the stream. The water was to flow over the weir and then under a suspended apron, rising and passing over another weir. The effect would be to take the clearest surface water over the weir in a

thin sheet, almost stopping the current, and giving the silt a chance to settle. By delivering the water into the bottom of the second compartment, a reasonably clear water was obtained in the upper part, which flowed over the second weir into a receiving basin. The speaker believed that the experimental plant on this system had proved successful so far as the removal of sediment was concerned. Mr. Tribus.

JAMES DUANE, M. Am. Soc. C. E.—It would be interesting to know the amount of leakage where the pipe line is under pressure, and whether or not this leakage is large where the pressure is heavy. The speaker also desired information as to whether the $\frac{1}{8}$-in. bead on one edge of each stave was a success. He questioned if a joint thus made, where the material was not perfectly homogeneous, would be as satisfactory as the ordinary radial form, and asked if a joint in which a bead or tongue on one edge of each stave engaged with a corresponding groove on the adjoining stave would answer better. Mr. Duane.

CORRESPONDENCE.

R. C. GEMMELL, Assoc. M. Am. Soc. C. E.—The writer desired to ask the author the following questions concerning the wooden pipe: 1. Should the lumber used for staves be entirely free from knots? 2. Is Oregon yellow fir good material for staves, and how does it compare with redwood? 3. Should the wood be dry and thoroughly seasoned before being milled? 4. Should the staves be coated on the outside with asphaltum, and, if so, how should the coating be applied? 5. In making butt joints, is it considered better practice to use metallic tongues than wooden splines, and how should the saddles be placed with reference to these joints? 6. Should the bands be cinched up very tightly at first or only moderately so, being left for subsequent tightening when the water has been turned on and the wood given time to swell? 7. What is the maximum distance apart that bands may safely be spaced when the pipe is to be under a very low head? 8. What is the maximum pressure under which wooden pipe may be used with safety? 9. What is the probable life of properly constructed wooden pipe under ordinary conditions? Mr. Gemmell.

Mr. Riffle. FRANKLIN RIFFLE, M. Am. Soc. C. E.—The author is to be commended for his systematic efforts to arrive at the exact cost of the several classes of work performed by day labor, but the utility of his carefully compiled results is questionable, owing to the peculiar financial situation, as elaborated in the paper. If the author had gone a step farther and separated the cost of work done on a cash basis from that which was done when the company was known to be in financial straits, a comparison could be made which would be both interesting and instructive. In addition to this it would also be possible to form a tolerably correct opinion as to what proportion of the increased cost of the work was due to its performance by day labor instead of by contract, a phase of the question which the author has apparently ignored. That the entire work could have been completed at a less cost to the company by an experienced and responsible contractor, goes almost without saying.

Some years ago, while connected with railroad construction on the Pacific Coast, the writer took the pains to compare the cost of "company" work with the cost of contract work, and was somewhat surprised to discover that in every case investigated the former exceeded the latter, the excess ranging from 25 to 100 per cent. During recent years, however, the Pacific Coast railroads have adopted the contract system in their construction departments.

The recently constructed water system of Portland, Ore., furnishes an instructive example to the engineer who may be ambitious to save the contractor's profit for his employer. While the greater portion of the work was performed by contract, there was considerable work done by day labor, under the mistaken idea that this method would ensure more satisfactory results. It is a significant fact that in the former case the work cost considerably less than the estimate of the chief engineer, while in the latter case the cost has already largely exceeded the estimate, and the work is still in an unfinished condition.

Exception must be taken to the author's criticism of the management for "having started in to pay cash for everything." The most satisfactory and economical method of performing work is unquestionably on a cash basis. The payment of the men on the fifth day of each month for work done during the preceding month, and the payment of merchant bills on the tenth day of every month, are certainly in accordance with sound business methods, and should not be con-

strued as an indication of "shortsighted business management." Mr. Riffle.
The grievous mistake made by the management was in beginning active construction before the necessary funds had been secured. This is a mistake that occurs altogether too frequently on the Pacific Coast, and it must be confessed that the preliminary report and estimate of the engineer are oftentimes responsible for it.

The author evidently laments the fact that the credit system had not been introduced at the outset, since this would have enabled the management to conceal from the laborers the awkward fact that they were working for a bankrupt concern, until the work was practically completed.

It is to be regretted that engineers of unquestionable honesty and integrity of purpose often consider it a duty they owe to their employers to bolster up shaky enterprises by deliberately misrepresenting their financial condition to contractors, laborers and material men. As a case in point the following instance may be mentioned: A municipality not many miles from San Francisco sold bonds to the amount of $175 000 for water-works construction, the amount being based on the engineer's estimate. The several divisions of the work were let to as many different contractors. The contracts all provided that 25% of the estimates should be retained until 40 days after the completion and acceptance of the work. A portion of the work, which largely exceeded the engineer's preliminary estimate, was not finished for six months or more after the completion of the other contracts. During this period the engineer studiously avoided accepting the completed portions of the work under one pretext and another, all more or less plausible, keeping the true reason to himself. He had discovered (what no one else knew) that the unfinished portion of the work was largely exceeding his estimate, and that the only way to keep the contractors in ignorance of the fact that there was not sufficient money in the treasury to pay them in full was to withhold the retained percentage, which, according to the contract, was not technically due until the work was formally accepted by the chief engineer. The result was that through this shrewdness on the part of the engineer the water-works system was successfully completed by the contractors, who were compelled to furnish the municipality with about $25 000 worth of labor and materials for which they were not paid, and may never be paid, since the laws of California are such that contractors

Mr. Riffle. have no redress against either municipalities or officials who may conspire to victimize them. It is to be hoped that when the much-talked-of code of ethics for engineers is finally formulated it will condemn in unmistakable language the reprehensible practice of sacrificing fair dealing to zeal and loyalty.

Mr. Greene. CHARLES W. GREENE, Esq.—The very comprehensive presentation as to the construction of these works leaves little opportunity for one who is not a member of the engineering profession to add anything. The writer desires simply to comment upon the construction narrative. Although the work was in progress when he assumed the presidency and management of the company, the greater portion of it was done under his administration. The author frankly acknowledges the cordial co-operation which was given him by the later management, but the difficulties in the way originated prior to the writer's administration. Could the author have known all the facts as to the embarrassments under which the management was laboring during all those months, he would probably have recognized that his department was not alone involved in the unfortunate conditions. While the company did not go formally into the hands of the receiver until December, 1893, at the time it passed into the writer's hands in the previous January and he became its chief executive officer, combining the two functions of president and manager, the primary causes existed which led to its final disaster. Those conditions he had, personally, no responsibility in creating.

Unfortunately there had been no settled business policy previous to that date, and although an immense sum of money had been provided for the company through his financial agency, there had been but little actual construction to show for it. The work upon this canal itself had been begun a few weeks earlier, and one of the first problems presented to him was whether it should be discontinued or carried forward. It was decided to go forward, believing that confidence could be restored among investors in the enterprise, and because the absolute necessity of the situation compelled this construction prior to a given date. Looking back at it and considering the hindrances one after another, the wonder is that it could have been accomplished at all, and but for the excellent administration of the engineering department, which was from beginning to end of the highest order, it could not have been. Necessarily, he was compelled to withhold, even from the

chief engineer, the extent of the difficulties which surrounded him and which were embarrassing the company's finances. It was one of those cases where a great work once begun could not be abandoned without great loss, and its salvation depended upon carrying it forward courageously to completion without an exposure of its weakness. This is neither the place nor the time to discuss these difficulties in detail, and the events which led to the final disaster. Mr. Greene.

It is the writer's wish and duty to confirm the opinion expressed by the author that under more favorable conditions the work accomplished by him would have been done at a minimum of cost and with a maximum of excellence. Engineers seldom have to meet a greater variety of problems in a construction of such magnitude than were presented in that, and, as the paper will show to the careful reader, there was from the beginning a comprehensive grasp of these problems in detail and entirety. Despite all the obstacles, engineering and financial, there was not more than the ordinary delay which attends such enterprises in the final completion, nor was there excessive cost, except as he has specifically accounted for it. If the saving had been affected for which he planned, it would have been so much less than reasonable cost to the company. When the water was turned into the canal there were no defects to remedy, except of the most trivial character, the skill, judgment and faithfulness of the entire engineering force being entirely proved by the results accomplished.

JAMES D. SCHUYLER, M. Am. Soc. C. E.—The works described in this interesting and elaborate paper are in the front rank among the high-class irrigation works of western America, and are creditable in design and execution, notwithstanding the financial difficulties that impeded their construction. The writer took occasion to visit the works shortly before completion. The stave and binder flume which forms so long a link in the conduit is a novelty that was specially interesting. It seems to be a type of structure that is particularly well adapted to the frequent changes that were necessary from canal or tunnel section to the circular form of pressure pipe, which was the case here, as well as to situations where it is desirable for economic reasons to make the depth as great as, or greater than, the width. In designing a conduit of this character and of the very large capacity of the one in question, which has to traverse a very rough country with slopes often steeper than 45°, the width of the bench on which Mr. Schuyler.

Mr. Schuyler. it is to rest is of importance, in order that the grading may be reduced to the least possible amount. Hence every foot that can be saved in the width of the flume is in the interest of economy of excavation. With ordinary flume construction it would be considered objectionable to give so great a depth on account of the extra bracing required, the length of sills needed, the number of side joints to keep tight and the greater width of bench required. The ordinary flume is made in its simplest form where it can be reduced to a single side-board on each side, 18 to 20 ins. in height, and the writer has found it preferable to keep to that plan, even where the width of flume reached 6 ft., rather than to increase the depth. With the stave and binder, however, it is possible to cinch up the side and bottom boards with a few turns of the wrench, and so the objection to greater depth is largely done away with. The only objection to the flume is its cost, and that may be modified to bring it within accessible limits. The figures of cost given in the paper would be of more value for application elsewhere if the cost per 1 000 ft. B. M. for lumber milled and delivered and the cost per pound and weight per foot of iron-work had been given. However, a flume that costs $2 45 per foot, set up complete on a steep mountain side, cannot be considered as extravagantly expensive when its large capacity is considered and its superior quality kept in view. Many irrigation corporations would have spent less in first cost, perhaps, but much more in maintenance and renewals.

The writer is inclined to disagree with the author as to the advisability of constructing wooden-stave pressure pipes without either burying them in the earth or applying some coating or covering for the protection of the wood. In the present case the steepness of sides of the gorges crossed justified leaving the pipes uncovered, and in fact it would have been exceedingly difficult and next to impossible to bury them, except at great cost, although in the writer's judgment it would have been highly desirable to do so, from the fact that they are now exposed to the danger of destruction from brush fires that periodically sweep up these cañons with terrific force, consuming everything in their path by the intensity of their heat. This is a danger that would be removed by burying the pipe in any location, but as there was no alternative in the present case but to expose the pipe to the weather, some preservative to prevent disintegration by the action of the elements should have been applied. To be sure paint,

coal tar or asphalt would be of no value in such a position of exposure, where the moisture oozing from the staves would prevent adhesion, but common whitewash would have acted admirably as such a preservative, not only of the pipe, but of the trestle as well. Mr. Schuyler.

The writer's experience with lime, thus applied, as a preservative of wood has been that it is superior to paint, lead or oils, and it has good resisting qualities in case of fire. For the exterior of flumes he has found it the best of all applications, asphalt being the best for the interior.

If, however, a wooden stave pipe is to be buried and kept full of water under pressure he is of the opinion that it is best to leave it entirely uncoated, and that the burying of the pipe will, under all ordinary conditions, be found to prolong its life, certainly so far as the preservation of the wood is concerned. Decay in wood is a process that takes place only in the presence of both air and water; exclude either element and decay is arrested indefinitely. The burying of a pipe in any close soil practically excludes the air from contact with its exterior, while the water, saturating the wood from the interior through to the outside, renders it practically rot-proof. The long exposure of a wood pipe to the powerful action of the sun and winds, even though it be saturated inside, is almost certain to bring about a disintegration of the surface if it has no exterior coating. The wood pipe built by the Bear Valley Irrigation Company in 1891, and referred to by the author, is evidence of a perfectly preserved pipe, although exposed to the open air. The writer believes that it was thoroughly coated with coal tar prior to its completion or use. It certainly has that appearance.

In reading the paper, as well as in looking over the work, the query is suggested as to why the wooden stave pipe, so successfully used in crossing three of the main drainage lines, should not have been also used for the crossing of Mill Creek. The stream-bed, consisting of cobbles and boulders, could have been crossed with a pipe with quite as great a degree of safety as the bridge, for it might easily have been buried to a depth as great as the bridge piers now reach, while the entire cost would evidently have been considerably less.

DAVID C. HENNY, M. Am. Soc. C. E.—In the part of the paper referring to wooden pressure pipes it is stated as one of the reasons for laying the pipe siphons of the Santa Ana Canal above ground, that the Mr. Henny.

Mr. Henny. wood, with free circulation of air around the pipe, is less liable to decay than if buried under ground. The condition upon which the life of wood in wooden pipe depends is its complete saturation. With the pipe exposed to the effect of wind and sunshine, the stave dries out to a greater or less depth from the outside, as atmospheric influences change and conditions are created not favorable to a long life of the outer portion of the stave. A cover of earth or even gravel over the pipe will check the drying-out process, leave the stave moist from inside to outside, and serve to exclude the oxygen of the air, which, in connection with moisture, is believed to be necessary to cause the wood to decay.

That the wood in the 48-in. stave pipe built by the Bear Valley Irrigation Company six years ago is perfectly sound, outside as well as inside, is not surprising to any one acquainted with the lasting qualities of redwood in more unfavorable circumstances. The upper end of this pipe line is buried, and as it may have been examined by the author it would be interesting to know how the condition of the wood compares with that of the exposed portion. This pipe is painted, where laid above ground, with what appears to be asphaltum, but the coating is now in very poor condition. A cover of paint applied to pipes will have the tendency to resist drying out, if the coat be thick and adheres firmly to the surface of the wood. It may be questioned, however, whether such a coating can be made to stick, even if first applied to the pipe when thoroughly dry, for the water will reach it from the inside and tend to loosen it and drive it off.

As it is generally held that wooden substructures, if sound and placed below the level of the ground-water, will last regardless of the character of the soil, it may be of importance to inquire to what ingredients in soil the author refers as possessing wood-decaying influences, and whether such ingredients have a similar effect on wood continually saturated, as in pipe. In the light of present experience, the writer is inclined to the belief that, so far as the wood is concerned, a covering of earth is to be preferred to exposure to the atmosphere. Liability to exterior injury from accidental or malicious interference and danger of fire and wind to supporting structures also largely operate in favor of burying pipes below the surface.

As regards the steel bands, it is certainly objectionable to put them in contact, even if thoroughly coated, with soil containing alkali, and

as with buried pipe the life of the steel bands may be regarded as the controlling element in the life of the entire pipe, there may be a gain in such cases in leaving the pipe exposed. Mr. Henny.

Metal elbows were deemed objectionable as very materially increasing liability to decay, leakage and failure at the joints. It may be laid down as a general proposition that joints in any kind of pipe are not desirable; yet it is believed that joints between wooden and iron pipe can be made in a thorough and substantial manner, neither jeopardizing the life of the pipe at the points of juncture nor causing trouble from leaks or danger of bursting. Ordinarily, joints of this class are made by providing the end of the iron pipe or elbow, whether made of cast-iron or riveted iron, with a strong and straight bell or socket 7 or 8 ins. deep, large enough to leave a space of about $\frac{3}{8}$ in. between the outside of the wood and the inside of the iron. This space is calked full of oakum as hard as the wood will stand. Joints made in this manner are tight under 200 ft. head. Sometimes only part of the space is calked with oakum, the remainder being filled with lead, but the softness of the wood does not allow the lead to be driven up hard.

It was stated that much of the lumber of the pipe staves used in the Santa Ana Canal siphons was quite wet. The terms "wet" and "dry" in connection with lumber are extremely relative, weight being, perhaps, the best criterion. The butt cuts of a redwood tree usually sink when dumped into water, and hence are called sinkers. The wood grows lighter from the bottom up, the weight of lumber, green from the saw, varying from 3 to 6 lbs. per foot B. M., the average for clear lumber, which all comes from the lower part of the tree, being about 4 lbs. when green, and 2.3 lbs. when bone dry. The weight of the pipe staves averaged 2.51 lbs. per actual foot B. M., which, since they were all cut from clear lumber and a large proportion from butt cuts, indicates a high degree of dryness, resulting from between one and two years' air drying in the comparatively moist and cool climate of the coast of northern California. And yet it was not surprising that the staves shrunk perceptibly after arriving in the hot and dry climate of southern California. All lumber coming from the North will do this unless it has been kiln-dried.

Kiln drying is not looked upon favorably where strength and durability are of importance. Lumbermen claim that it takes the life out of the wood, which, if so, may be due to molecular changes in the fiber

Mr. Henny. of the wood or in the preservative acid it contains. As water is depended upon in the case of pipe to preserve the wood, the latter would be of less importance, but it is certain that kiln drying causes the wood to check more or less badly, according to the temperature of the kiln and the greenness of the lumber, and moreover damages it by forming air spaces in the interior of the wood, sometimes revealed by a slight bulge on the surface, produced by the generation of steam, for which there was no ready escape. For pipe staves, air drying is to be preferred, and it is believed that better pipe can be built with partially dry staves than with staves run from kiln-dried lumber.

The use of partially wet staves does not imply leakage at the time of filling, except where the pipe is exposed, and the shrinkage continues after the release of the initial strain on the bands and is not off-set by a further screwing-up of the nuts.

It must be remembered that redwood is soft, and that by hard cinching the staves are materially compressed. If the pipe be backfilled, even with but a few inches of earth, immediately after the final cinching of the bands, shrinkage almost entirely ceases; what little there is is counterbalanced by the elasticity of the wood endeavoring to expand, and the pipe will stand for an indefinite time without becoming loose.

To illustrate the effective manner in which earth covering protects wooden pipe from drying out, it may be deserving of mention that in January, 1894, a short piece of pipe was cut from a 24-in. redwood pipe line laid in the dry soil of the Capitol Hill section of Denver, Colo., in April, 1885, which had not been used since February, 1890, and was found to be still thoroughly water-soaked.

In milling lumber for pipe staves, proper allowance should be made for probable shrinkage and compression, if the completed pipe is not to show too small a diameter, and the use of an objectionable and troublesome narrow stave is to be avoided. James D. Schuyler, M. Am. Soc. C. E., describes in his paper on "The Water-Works of Denver,"* the construction of a 34-in. redwood pipe, and records a shrinkage in the 20 staves that formed the pipe of as much as 3 ins., or 2.6% of the circumference. Presumably this was the combined effect of shrinkage and compression from cinching.

In the construction of the 9 miles of 24-in. redwood pipe at Butte

*See the *Transactions* of the American Society of Civil Engineers, Vol. XXXI, p. 135.

City, Mont., an average reduction of about 2% was observed, with somewhat drier lumber and climatic conditions very much the same as in the case quoted by Mr. Schuyler; and as near as could be told from careful measurements, about one-half of this, or 1%, was due to compression alone. In 8 of the 9 miles the use of a narrow stave or filter was avoided by milling the staves to a width 2% in excess of what was theoretically required. The same allowance of 1% was made for the compression of the Santa Ana Canal pipe staves, and an allowance of but 0.5% for shrinkage, since the lumber was comparatively dry, as stated above. Thus the full diameter of the pipe was attained after cinching, without the use of an extra filler. Mr. Henny.

Objection may be made to the use of partially wet lumber for pipe staves on the ground that uneven shrinkage after milling destroys to some extent the desired uniformity of cross-section of the stave. As a precautionary measure pipe staves are stacked close, and so far as possible, kept from drying out by protecting them from sun and rain. No serious results, however, need be anticipated from any ordinary unevenness of fit of the butt end of one stave against that of another, such as may be caused by uneven shrinkage, for it is readily taken up by even partial cinching, at least in the case of redwood, its compressibility being in this respect an advantage.

In the design of the 32-ft. truss at the bottom of the Deep Cañon pipe crossing, the load, owing to the resultant thrust consequent upon the curvature of the pipe line, has been neglected, as explained by the author, although it averages at that point 485 lbs. per lineal foot as against 1 173 lbs. for the weight of the pipe and water, the latter having been used as a basis for the proportioning of the truss. The fact that the plates of the truss rods have never been brought to their full bearings indicates that the truss, as such, carries less weight than was intended, and proves the pipe, as a tubular girder 32 ft. long, to have greater stiffness than the truss.

While the pipe may thus act safely in part as a girder for a comparatively short span, it is evident that it cannot be expected to do so for the entire length of the trestle. Absence of anchorage on the side hills precludes the idea of the pipe performing the duty of a cable in a suspension bridge, which would in any event be objectionable, as very serious longitudinal strains would thereby be induced. The resultant thrust for the 250 ft. of pipe on the trestle averages 405 lbs.

Mr. Henny. per lineal foot as against 1 169 lbs. for the weight of water and pipe, and is therefore an item not to be neglected in the design of the trestle. Nor should it be overlooked in the spacing of the sills immediately under the pipe, for although the pipe may be capable of transmitting a load from a weak sill to a stronger one, such transmission can only affect the local distribution of the load. In fact, the very stiffness of the tube demands stronger sills or closer spacing of them than would be necessary for a more pliable top load, as it is evident that its rigidity will not allow it to follow an uneven deflection of the sills or settling of the structure, or permit it to correct any difference in the tightness of wedging up under the pipe. In this connection it may be mentioned that the sills were originally spaced 6 ft. between centers on the trestle, and that their number was afterwards increased by the placing of intermediate sills. It is, of course, understood that the resultant thrust in the case under discussion is nothing but the transmitted weight of water from the hillside portions of the pipe line. Its effect has here been discussed in some detail, simply because it is much greater than the writer at first sight expected with a curve of so large a radius.

The junction bays connecting the pipe with the flume are almost perfect from a hydraulic point of view. From a constructive standpoint, it may, perhaps, be asked why the entrance of the pipe was not entirely dropped below the bottom of the flume, so as to insure its submersion even with the smallest flow of water. It is evident that this would have involved an increased cost, which may not have seemed justifiable.

The U-shaped flume is a departure from ordinary practice, and therefore deserves particular attention. It must be conceded that, as developed by the author, it has numerous and great advantages over the wooden box flume, and that it is excellently adapted to the case. Moreover, results have shown it to be thoroughly watertight, as might have been expected. The author states that it is virtually the lower half of a wooden pipe, laid to grade, and this analogy naturally leads to the question why the staves were dressed to flat sides instead of with rounding or cylindrical surfaces, as is usual with pipe, the cost of working being the same in both cases. It seems to the writer that the better bearing that would thus have been obtained for the steel bands on the wood, and for the entire trough in the yokes, would have been an advantage.

The steel bridge and flume were selected as the best solution for crossing Mill Creek. It appears that on the basis of contract prices, supposing no heavy flow of ground-water were encountered in the deep cross-cut, a wooden pipe laid well below the surface of the creek bed would have resulted in a saving, even if its duplication would have been necessary in the near future. Mr. Henny.

The writer has raised these points, not because he doubts that the author has had excellent reasons for the manner in which the many difficult problems have been solved, but because he thinks an explanation would be interesting.

L. J. Le Conte, M. Am. Soc. C. E.—The author's contribution is instructive and worthy of careful study. There may be good reasons for adopting such high velocities for flow of water, viz., 8.5 to 10 ft. per second for flumes, siphons and tunnels, while the open canal velocities are a little less than 5 ft. per second. But it seems to the writer that waters transporting sand in suspension and coarser material rolling along the bottom of the conduit will undoubtedly scour the lining of the waterway to a serious extent. The plan of construction adopted for combination flumes is very economical, and its capacity for discharge must be excellent. The only feature which seems questionable is its durability. This is a matter which experience will decide. The depressed tunnel idea with a lining composed of concrete and an inside facing of wood, always submerged in water to prevent decay, seems to be economical, all things considered, and admits of wide application. In regard to double siphons used across the deep ravines, as far as the writer is able to judge from the data, they will cost when completed about $18 per linear foot. Excepting Tunnel No. 7, this is the most costly portion of the entire work, and the writer is of the opinion that this may be open to some criticism. In the lowest portions of siphons Nos. 2 and 3, the steel bands are described as being 2½ ins. between centers. This would imply that there was in this portion at least more than enough steel in the bands to make a complete steel pipe of the same diameter. Mr. Le Conte.

The great practical advantages of the wooden stave pipe over wrought iron or steel pipe stand out prominently when conduits of large size are subjected to comparatively light pressures. In case of iron and steel it is necessary to put in a large percentage of extra metal over and above pressure requirements in order to prevent the

Mr. Le Conte.

pipes from collapsing under their own weight while empty. Hence where pressures are light and the diameter of the pipe large, the stave pipe is certainly much cheaper and more practicable in every way. But when the pressures are high the advantages all shift over to wrought iron and steel pipe, because then the calculated thickness of metal to meet the high pressures is sufficiently great to avoid the danger of collapsing when the pipe is empty. In short, no extra metal is required for stiffening. In all such cases the steel pipe is cheaper and better. The only questionable feature about the banded wooden pipe is its durability, and experience alone can decide it.

The idea of laying the siphons on top of the ground seems to be altogether reasonable in this locality. Of course iron and steel siphons have been laid in the same way many years ago, especially where the nature of the soil corrodes the iron. The section adopted for the open canal seems to be well adapted to meet the great variation in volume of water to be handled during the year.

There are some points in the location which might be criticised. There is no preliminary work which requires greater care and judgment to obtain the greatest economy than the location of an aqueduct in a rough country, broken and rocky. Such was found in this case.

The problem is not only the selection of the simplest line with reference to the quantity of work, but also with due regard to the class of work to be constructed. The most economical location, other things being equal, is generally found to be in light cutting, and therefore the line should be laid out with chief reference to this fact. Siphons should also be reduced to a minimum.

In the matter of lined and unlined work the choice is of paramount importance since the one may be roughly estimated at three times the cost of the other. Consequently it should be the constant study of the engineer in charge to avoid as much as possible the necessity of lining the work.

In regard to the actual cost of the work exceeding the estimates, the writer would say that in this class of work it is absolutely impossible to estimate with exactness, because the quantities to be dealt with are largely unknown and variable. Even with complete maps and carefully made test borings, they can only be ascertained approximately. The grand average cost per mile, $39 900, is remarkably low. The writer would like to know the chief reasons why such great variations in fall per mile and velocities were adopted on this work.

WILLIAM HAM. HALL, M. Am. Soc. C. E.—Mr. Croes' criticism on the point of possible excessive cost of surveying to save "a few dollars in construction" on the flume line might be unanswerable were it not for the fact that the saving of cost was not the only object in view. A bolder and less painstaking method, it was believed, would have resulted in two faults in construction—the first, excessive and unnecessary timber substructure work, thereby increasing perishable parts at some places, and the second, excessive side cutting, thereby increasing the probability of slides and falling rocks at other places. Even on the point of economy alone, the author believes he could have shown that it paid to be most painstaking in location, and Mr. Croes has himself pointed the reason why, in kindly calling attention to "the difficulties due to the nature of the country." Mr. Parsons, also, has in his remarks indicated another reason why the engineering work may have been, in some respects, excessively expensive; the variety in construction. and the detached workings on the several parts. There are still other reasons which the author has not brought out because of a desire to avoid unpleasant reflection, and to hold the paper and discussion within bounds. It is proper to say, however, that the real and material excess of cost in this branch of the work was not the fault of the engineers. Mr. Hall.

The question of the amount of leakage of the wooden pipes, brought up by Mr. Duane, is difficult to answer quantitatively. When the pipes had been finally cinched and became fully settled and swelled, there was little or no leakage; they were practically, if not absolutely, tight. At one time, in the course of experience with the Deep Cañon pipe, however, it leaked like a very much decayed and broken sieve. The circumstances were these: Construction on each of the pressure pipes was begun at the lowest point or bottom of the U, and progressed thence up the slopes either way, so as to keep the arms of about equal length at all times. It was desired not to let the pipes remain long after banding without water in them, and to have them loaded when the end joinings were made. As a supply could not be delivered to them in time by way of the conduit itself, they were each gradually filled, as completed, by using a small steam pump taking its supply from the cañon stream underneath. One or two rather bad leaks in the Deep Cañon pipe had wasted much of the water out of it, after the pumping plant was moved to Morton Cañon and before the flow came

Mr. Hall. through the conduit. The fact of the wood having been wetted seemed to make it shrink the more. The author desired to see what the effect would be, so it was purposely not tightly reinched before the water came in. A force of attendants was assembled with all necessary tools, and the stream arrived. To say that the result was interesting is but lamely expressing the fact. It was picturesque, and for a short time, just a little alarming. The water spouted and streamed from almost every seam; but all hands, though soon drenched to the skin, worked with a will, and in about an hour the 1 000 ft. of pipe had almost ceased to leak. An inspection several days afterward showed practically a water-tight pipe, there being a few drips which were stopped by tightening a band or two at each point.

Replying to the questions asked by Mr. Gemmell: (1) Anything like a shattered or loose knot in pipe stave lumber certainly would be detrimental, particularly so if in the edge of the stave. It may be said as expressive of a practical shade of meaning on this point, that pipe stave lumber "should" be free from knots, but that very good pipes may be built of lumber having (some) knots in it. Certainly in specifying for staves of redwood, which can be had free of knots, they should not be in it; but in specifying for some other kinds of lumber, used locally for economy, they may be admitted, if sound, and not in the stave's edge. (2) The author has never constructed or supervised the construction of a pipe of Oregon yellow fir, but he believes it to be a suitable wood for the purpose, under some conditions, though not nearly so good as selected redwood. (3) The wood certainly should be well seasoned before being milled; but it is impractical to specify that it should be "dry and thoroughly seasoned." For instance, it is questionable whether "dry and thoroughly seasoned" lumber, according to the standard of arid southern California, could be had from the humid regions of either the Oregon fir or the redwood mills. (4) The question of coating the staves is spoken of elsewhere in replying to Messrs. Henny and Schuyler. (5) The author prefers metal tongues to wooden splines for closing the butt joints. Driving the staves to place and afterwards cinching the pipe sinks the metal into the abutting and adjacent staves, and insures a tight joint. The author thinks that the wooden spline or tongue will not act to so good a purpose in this. Moreover, he believes that decay will start in joints closed by wooden splines long before it will in those closed by metal tongues.

Mr. Hall.

These are points of opinion, but answer the question as put, so far as the author can do so. (6) The bands should not be cinched, before water is taken in, as tightly as ultimately required. This is a point somewhat indeterminate, to be decided by judgment founded on practice. The author does not here attempt reasoning on it. The engineer to the Excelsior Wooden Pipe Company has recently had a spring strain-indicator made, to test the strain on pipe bands in cinching. A series of experiments with some such device would, doubtless, be most instructive on the point of amount of cinching desirable, both before and after water is taken into a pipe. (7) The maximum distance between bands on pipes of moderate size, under very low pressure, might well be varied somewhat with the thickness of staves, the thicker stave admitting the greater space. The author thinks that the greatest allowable distance would always be found between 12 and 18 ins., however. The question of strength of banding is not raised in this connection. (8) The author cannot see how he can answer Mr. Gemmell's eighth question: "What is the maximum pressure under which wooden pipe may be used with safety?" That will depend on the size of the pipe. Moreover, such pipes may be made "safe" under pressure and conditions such that they would be undesirable on the score of economy, as compared to steel pipes. The metal banding, of course, takes the strain of pressure. Having fixed on the factor of safety for the metal, and having had the bands upset for threading so as to get as much strength in the threaded part as in the plain band, the practical limit of safety would seem to be reached when, to withstand the pressure strains, the bands have to be brought so close together that the screw nuts can no longer be operated. In addition to the water-pressure, imprudent cinching while the staves are dry will bring the swelling strain of the wood excessively against the banding and the limit of safety may from this cause be overstepped before one knows it. The strain indicator, spoken of above, will be specially useful in the study of this question. (9) The probable life of wooden pipe is referred to elsewhere.

The remarks of Messrs. Schuyler and Henny about the wooden pressure pipes of the Santa Ana Canal work are welcomed as of special value. These gentlemen have had wide experience with such construction, and they have made in this discussion some suggestions which the author accepts and others which may well justify difference

Mr. Hall. of opinion on points raised. Mr. Schuyler's suggestion of whitewash for the trestles is good. The trestles would have been whitewashed before now had the author remained in charge of the works after construction, with means at command. That the pipes would have been benefited by this coating, at first, however, the author questions. It can be put on at any time. Will the lime do the steel any good? May it not do harm in the threads of the bands, confessedly the weak point of the tube construction? As there seems to be but little difference of opinion on the vital point, that the life of the pipes will be measured by the life of the bands, the thought occurs that anything put on the bands, as, for instance, a lime paste, which is not preservative of the steel and which will hold moisture on it, may hasten its rusting, and unquestionably will make it more difficult to apply thoroughly any preservative paint whenever necessary to use it. That whitewash for the outside of ordinary flumes is beneficial, the author freely admits. But a steel-banded pipe, under pressure and with water oozing and evaporating from its pores, presents different conditions. The author seriously doubts the efficacy and even the admissibility of whitewash on such pipes. In a less degree, and for similar reasons, he doubts the advisability of whitewashing the flumes of the Santa Ana Canal; though had he continued in charge, had the company not gone into the hands of a receiver, he would have tried this wood perservative on a portion of the fluming. There are other flumes, short pieces of the ordinary wooden box kind, not bound with steel, which are whitewashed in the Bear Valley system of works, and there are several longer box flumes in other works in the immediate neighborhood, thus treated, and, apparently, to advantage.

On the point of comparative life of wood in pipes (1) in the open air, and (2) when buried below air influence in close-packed earth which is free from special wood-destroying agents, and will remain moist, there is really no difference of opinion. The author accepts what Messrs. Schuyler and Henny say on this point as literally correct, but the practical application is quite a different thing. Mr. Schuyler concedes that it would have been impractical to have buried the Santa Ana Canal pipes. Mr. Henny seems to think they might have been buried if metal elbows had been introduced. That a good metal elbow or joint can be made in such a pipe—that is, good as an elbow or good as a joint—is true. But its presence is objectionable (1) as decreasing ca-

pacity, (2) as contributing to early decay in bolt holes and oakum joints, (3) as presenting a point specially liable to rapid abrasion by heavy sands and gravels, (4) as presenting a point liable to catch a drift stick or plank and ultimately cause clogging by accumulating weeds or brush likely to be brought to the flume and thence to the pipe, by small slides or rolling rocks from the mountain side, which would not breach the flume. Mr. Hall.

As to the broad question of the advisability of burying steel-bound wooden pressure pipes in general, there is more difference of opinion. Messrs. Schuyler and Henny seem to think the cases rare when such pipes should not be buried. The author cannot join in this opinion. Mr. Henny touches the key-note of the author's contention in admitting that "with buried pipe the life of the steel bands may be regarded as the controlling element in the life of the pipe"; and he recognizes the deleterious effect of alkali in soils, on the steel bands. Now, the bands can be cared for and replaced with the pipe above ground; they cannot be, if buried. The question would then seem to be: Will the wooden staves of a pipe which is kept saturated above ground last longer than the steel bands of a pipe kept saturated underground? The author thinks, as a general thing, that they will. And beyond this general proposition lies the danger of sometimes encountering unlooked for and specially unfavorable conditions underground, and not realizing them until too late.

As to the advisability of coating stave pipes when placed above ground. If a coating has been or can be suggested which (1) can be put on after the pipe is ready to receive the water, (2) can be made to stay in good condition and uniformly effective, (3) or can be effectively renewed, (4) will tend to preserve both the wood and the steel, and (5) will not render the pipe much more inflammable and subject to destruction by brush fires, the author will admit that the pipes might be covered with it to advantage, if it would pay to do so. Coal tar put on very hot and thin, so as to be absorbed by the wood, is the only thing which the author knows of that will answer these requirements in some degree. But can it, practically, be thus applied when the lumber is dry enough to take it? It could not have been on the Santa Ana Canal pipes, because the lumber never was dry enough to take a coating. Moreover, if it entered the pores sufficiently to preserve the wood, it would keep the moisture from the outside, and thus (besides

Mr. Hall. being inflammable itself) render the pipes more liable to catch fire from brush fires.

The author cannot understand the philosophy of maintaining a claim of long life for wood pipe, based on the condition of water saturation through the outside, and then wanting to apply some gummy substance into those pores which will prevent the water from thoroughly penetrating them. Mr. Schuyler says: "Saturating the wood from the interior through to the outside renders it practically rot-proof." That is precisely the condition which the author would seek to maintain by not coating with hot coal tar, which, in order to hold on, must penetrate and close the pores. It is because of the creosote in coal tar that it preserves wood. This volatile oil evaporates in a few years from the wood surface, leaving only a gummy substance in the pores. There is no evidence that this gummy substance is a preservative. Railroad structure timbers often rot very quickly after the creosote has been evaporated or washed out from their coal-tar coating. A new coat cannot be made to take hold while the pipe staves are wet, and it may be inconvenient and certainly would be harmful to empty and dry the pipe sufficiently to allow of effective recoating.

Mr. Henny says: "With the pipe exposed to the effect of wind and sunshine, the stave dries out to a greater or less depth from the outside, as atmospheric influences change, and conditions are created not favorable to a long life of the outer portion of the stave." Now, if this be true of uncoated staves, with a hydrostatic pressure behind them supposed to be sufficiently heavy to drive water enough through to moisten and keep moist the surrounding earth, were they buried, is it not equally true of staves coated with coal tar? A coating of coal tar, acting as a cuticle or skin, is far from airtight. The air gets to the wood quite freely after two or three years, at most. Coal tar coatings deteriorate very rapidly when exposed to freely circulating air and sun in southern California. The creosote is soon gone. If the water is prevented from oozing out of the pores within, it is the tar gum soaked far into those pores which stops it. The author thinks this will not conduce to the life of the outside part of the pipe, concerning which Mr. Henny is solicitous if the pipe is not coated. Or if the water is not prevented from oozing through by the gum stopping the pores, then does it not conduce to the early washing away of the preservative creosote? The author thinks it may. And in this

condition may it not thereafter be the water and not the coal tar which will be the preservative ? Mr. Hall.

But why, it may be asked, coat a wooden pipe when buried in earth, if it is not coated when exposed in air ? Simply because the coating, when covered in from the sun and free circulation of air, preserves both the wood surface and steel from harmful soil influences, and stops the pores of the wood, keeping the moisture away from the steel bands. Earth is sufficiently dense and close to preserve the coating, and the coating, under these conditions, preserves the pipe, both wood and steel parts. But earth is frequently not sufficiently airtight or free from alkali to preserve wood wetted from one side only, or to preserve steel kept moist.

The author presents these arguments to promote thought on the part of those who may read them, and to stimulate observation by those having opportunity. They are not advanced dogmatically. Being himself slow to accept the older theories and conclusions which have not as yet been proved by practice, and which may have been arrived at without due reasoning, he cannot expect such experienced practitioners as Messrs. Schuyler and Henny to accept his newer views on this point without first having strongly presented the old case. This they have now done.

That the 2 400 ft. of Santa Ana Canal wooden pipes are exposed to brush fires by not being buried, is true. But so are the 14 000 ft. of flumes. And as a patrol has to be maintained to look out for the flumes, and will have to walk the pipe location in so doing, and as a most effective fight can be made against fire where water is had under pressure, as in a pipe, it does not seem that much additional risk, in the aggregate, is run on this score by having the pipes above ground.

As engineer and manager to the pipe company, Mr. Henny seems to have thought it a criticism that his stave lumber was wet when it was expected to be well seasoned. Criticism was not intended. The idea was to record a fact, which, under the circumstances, could not have been avoided, and to point to the necessity for taking lapse of time and season of year into consideration in drawing specifications for pipe lumber. The discussion on this point brought out from Mr. Henny, however, is a helpful contribution to our knowledge on the subject.

Mr. Henny says : "In the design of the 32-ft. truss at the bottom of the Deep Cañon pipe crossing, the load owing to resultant thrust

Mr. Hall. consequent upon the curvature of the pipe has been neglected, as explained by the author." This statement is not correct. The fact is that, although "the writer believed there was no necessity for giving the trusses additional strength," such strength was planned for. The plan of the work calls for four trusses to support the two pipes, two at the center and one each side of the full-width bents (see Fig. 9, Plate IX).* Only two of these trusses have been built, there being but one pipe as yet to support. As Mr. Henny has proceeded, the author understands, on the supposition that there were to be only three trusses, and as he has misunderstood the wording above quoted, he is in error as to the load-supporting provision made and to be made in the 32-ft. central span. The author believed there was no necessity for the provision, but it was actually planned for and made in the trusses, as far as constructed.

Again, Mr. Henny, admitting that "the pipe may thus act safely in part as a girder for a comparatively short span," the 32-ft. span in question, at the center of the trestle, says, "it is evident that it cannot be expected to do so for the entire length of the trestle." And he concludes that the effect of the thrust-resultant due to the curvature is "an item not to be neglected in the design of the trestle." In this he is, in a measure, right, but he is again mistaken as to the pertinent fact of the Deep Cañon trestle case. He has gone on the assumption that the author's remark about provision in the central span trusses was intended to apply to the design of the entire trestle. In this he is mistaken. The words were: The author "believed there was no necessity for giving the trusses additional strength," etc. Nothing was said in this of the trestle. Moreover, Mr. Henny has assumed that the trestle finished for use with one pipe is complete for the support of the two projected. In this he is also mistaken. The plans for completing the work, when the additional pipe is put on, call for (and have called for, from the time they came under the author's personal supervision, before the work was erected) the introduction of two posts from sill to cap in each bent, in addition to those now in the structure. As Mr. Henny's idea in this connection rests on a wrong assumption, it is unnecessary to combat it. Fig. 9, Plate IX, shows the head of double posting in the center, which as yet built is but single for the one pipe. The fact is that provision has been made sufficient to meet the extra load which theoretically might be placed

* Page 83.

upon the trusses and trestle from the cause Mr. Henny indicates. But the fact remains that the author does not now and never did believe that such load would ever reach the center span trusses in any considerable degree. And, hence, in his original draft of the paper, he referred to this as a "supposed load" which "theoretically would be consequent," etc. That such judgment was correct with respect to the 32-ft. truss part of the work is well stated by Mr. Henny himself as follows: "The fact that the plates of the truss rods have never been brought to their full bearings indicates that the truss carries less weight than was intended." The pipe has taken up the strain produced by the excess of hydrostatic pressure on the outer side of the curved portion, as the author believed it would. But the conclusion next drawn by Mr. Henny on the basis of this fact is not sound. He says "and proves the pipe as a tubular girder, 32 ft. long, to have greater stiffness than the truss." It would only seem to prove the pipe to have greater stiffness than Mr. Henny thought it would have as a girder for the 32 ft. As the truss has not been tested (the pipe holding the strain up from it), how is it possible to say that the fact cited proves the pipe to be stiffer than the truss? The truss has not sagged, it has not been tested. Mr. Hall.

The author does not contend that no part of the thrust-resultant, to which Mr. Henny alludes, will reach the trestle and thereby increase the load. He wishes to be understood as contending only that the problem is an indeterminate one; that it was unnecessary to make the full provision theoretically demanded; and that the somewhat arbitrary provision actually made was sufficient. In other words, that this was a case in which theory and formulas were not to be depended upon, except to indicate an indefinite danger.

There were two errors recognized by the author as made in the construction of this trestle. One was in setting grades and then afterwards trying to correct 0.1 ft. error by dapping a number of the bolsters or sills (the cross-ties supporting the pipe) to the stringers on which they rested. Each such sill was cut at each end, 0.1 ft. or less on the under side, and a number cracked when the weight came on them. So, to correct this, the total number was afterward doubled, as mentioned by Mr. Henny. Mr. Henny in this connection has made a good point in the following words: "The very great stiffness of the tube demands stronger sills or closer spacing of them than would be

Mr. Hall. necessary for a more pliable top load." If there was error in design in this trestle, it was in not allowing sufficient margin in the dimensioning and spacing of the sills for effect of uneven distribution of the load. The effect was made apparent by the cracking of sills which were dapped as described.

In his reference to the pipe junctions, Mr. Henny overlooks the fact that the plan for the lower bay to each pipe makes provision for gates whose operation would keep the pipes constantly full, thus preventing the result he speaks of as consequent upon the pipes drying out at their upper ends when very little water is running. This idea is referred to on page 95 of the paper, in connection with the wood-lined tunnel, and on page 140, in connection with the wooden junction bay; and it would have been apparent for the other cases had the plan of one of the masonry down-stream bays been appended to the paper. In many such details, the work as constructed is not complete, as the author tried to make clear. Repetition of explanation in the paper had to be brought to an end somewhere.

Replying to a question by Mr. Henny: The staves of the flume were not dressed to a round surface on the outside, because to have done so would have very materially diminished the thickness of their bearing edges, and the author did not think the advantage gained by a snugger bearing for the bands and ribs against the staves, on the outside of the shell, would compensate for the disadvantage of the thinner bearing of the stave edges against each other. He had in mind two facts: (1) that the bands would take neat bearings by sinking somewhat into the wood at the angles made by the stave junctions, and (2) that the flume shell had to act as a box-girder, carrying its load between 8-ft. spaced supports, and that in cinching it tight enough for this duty, $\frac{1}{8}$ in. to $\frac{3}{16}$ in. additional thickness of stave and width of bearing in the shell seams would make a big difference in resistant power.

Replying to the question raised by both Messrs. Schuyler and Henny: The bridge and flume were built for the Mill Creek crossing in preference to laying a pressure pipe for the following reasons: The author does not think it would have been good or safe construction to have laid a wooden pipe across that torrent bed without setting it in concrete and paving it over in a somewhat expensive manner. Such torrents do strange things in dealing with a refilled trench across their

path. A pipe sufficiently large to carry the ultimate volume of 240 second-feet, thus laid, would have cost more than the bridge and flume. A pipe to carry the half-flow, 120 second-feet, thus laid and with the necessary junction structures at the ends, would have cost nearly as much as the bridge and the flume. Subsequent duplication of such a pipe, to carry the other 120 second-feet, would bring the cost to more than the bridge with the flume enlarged to full capacity for the 240 second-feet. The buried pipes could not have been drained without pumping them out or extending a drain pipe from them far down the wash. This latter would have been liable to clogging with silt, and would have made the cost mount up to much more. It would have extended to the land of others. The company did not have right-of-way for it, and could not have secured such right-of-way without a suit for condemnation. The pressure pipes would have acted as sand-boxes at the period of low flow each year, and would have had to be cleaned, after drying them, by hand labor. This labor could be performed well enough if a 6-ft. pipe had been laid for the full capacity flow; but could not be in a 52-in. pipe for the half-capacity. Using either of these sizes, there would have been a material loss of grade elevation by the pipe as compared to the flume, and it was not at disposal to spare. Mr. Hall.

In this connection the author desires to explain a point omitted in the paper, namely, that each of the cañon pressure pipes was intended to have a large blow-off valve in the bottom of its lowest point for the purpose of annual clearance. These valves were designed, made and delivered, but not put in place before the company's failure.

Replying to a question by Mr. Le Conte: The variations in grade slope and consequent velocities were made for the different classes of conduits, principally for reasons of economy. The cañon flume, with 9.71 ft. per second (calculated) ultimate mean velocity, cost over all $4.50 per linear foot. The paved canal, with the corresponding velocity, 4.94 ft. per second, cost $3.75 per foot in length. To have lowered the grades, increased the section and diminished the velocity in the flume would have increased the cost more than could have been saved by increasing the grade, diminishing the section and increasing the velocity in the canal part of the work. This is equally true of a comparison between the pipes and the canal, while as between the tunnels and the canal the difference of cross-section and of velocity might

Mr. Hall. with economy have been made still greater. But the tunnels, flumes, pipes and walled canal, whose calculated velocities all range between 8.36 and 10 ft. per second (not a wide range), closely follow each other, alternating in the line. The water will have no great variations in velocity through this Division I, as shown by these calculations. Moreover, these limits of variation are probably extreme, too low for the walled canal (8.36 ft.) and too high for the tunnel (10.01 ft.). See page 153 of the paper.

Now, equating all of this division, with a probable mean velocity of 9.5 to 9.7 lin. ft. per second, against the canal constituting the bulk of the conduit in Division II, with its corresponding velocity (4.94 ft.), to have equalized the velocities at all would have increased the cost very much. Such comparative estimates were made by the author personally in studying the original general design, and have since been checked in the light of experience on the work.

Mr. Le Conte's suggested reason for keeping down the velocities in the flume, pipes and lined tunnels to avoid scour from transported sands and gravels "rolled along the bottom" may not appear sound when one comes to consider it. Given a load of sand and fine gravel, which, at a mean velocity of 5 ft. per second, would be for the most part carried on or near the bottom of a conduit, thereby wearing its surface away, with a mean velocity of 10 ft. per second, this load will be carried up in the body of the stream and will not wear the channel bottom. The author has known instances of precisely this phenomenon, lined conduits which suffered greater wear at periods of low flow, low velocity and least sand volume than at a period of full flow, high velocity and greatest silt presence. Again, if anyone desires to learn a practical lesson on this point, let him go to a conduit carrying heavy sand-laden waters. Let him remove his clothing and wade in where the current is slowest. There he will feel sands moving on and near the bottom over his feet and around his ankles, wearing the channel lining. Comparatively little sand will be felt against the skin toward mid-depth or higher of the stream. Then let him wade in where the current is swift, stronger than he can stand, where he has to be supported to maintain a footing; he will there feel little or no sand on the bottom, but the skin will be made to tingle by its pelting up and away from the bottom. The effect is striking; the author has frequently tried it.

The lined conduits wear out on the bottom where sand "rolls along." If it did not roll along they would not wear out, for the sides, which are struck by the particles held in suspension as much as the bottom is struck by them, do not wear out. The best solution of such a problem is to clear the water of sand and gravel which cannot be carried in suspension, and then run it so fast that all else is kept suspended and not rolled along. Mr. Hall.

In the Santa Ana Canal case the waters are to be diverted from a stream having velocities, at flood, of fully 10 ft. per second. To prevent such sands as these waters carry and as would be brought into the headworks, over the weirs described, from rolling along the bottom of the conduit and wearing it, the author believes the high velocity of nearly 10 ft. per second in the flumes and pipes is desirable.

Mr. Le Conte's point as to the cost of the double pipe crossings suggests one possible application wherein it might be well taken, namely, in the case of Warm Creek crossing. Here the pressure head, about 60 ft., would have admitted of a single pipe large enough to carry the full 240 second-feet, being put in. With this single pipe, the junctions could have been made from flume to pipe and from pipe to flume again, without any masonry structures, by simply rolling over the flume sides to form the pipe top, at the upper end, and then rolling out the pipe top to form the flume sides again at the lower end. This saving in masonry junction bays, would have gone far toward paying for the larger pipe, and the ultimate saving would have been about $750. But there would have been over $750 more in the work now, and to remain there, with its interest, until required to meet the full demand. Moreover, there are advantages in having the two pipes as against the one.

The Deep and Morton Cañon crossings have pressures too high to admit, in the author's judgment, of introducing one pipe to carry the full flow volume at about the proposed velocities. The distance around each of these cañons on a flume grade would have made the aggregate cost greater than that of the double pipe crossing.

Mr. Le Conte's reference to the amount of steel in the bands at the lower parts of the deeper crossings being sufficient to make an adequate steel pipe suggests this: Preliminary estimates from manufacturers as to cost of steel as well as wooden pipes for the crossings were obtained before choice was made. The wooden pipes were found to be

Mr. Hall. much the cheaper by any adjustment or planning that could be suggested.

The author does not understand Mr. Le Conte's general remarks concerning location studies and relative cost of lined and unlined work, when applied to the subject in hand. There was no possibility of constructing any part of this conduit as an unlined work. This the author tried to make clear in the original article. As a general proposition, however, Mr. Le Conte is right, and his remarks add value to the discussion. It is worthy of note, however, if Mr. Le Conte intended his remarks to imply that, possibly, greater care might profitably have been taken in studying location, Mr. Croes has thought that, possibly, unnecessary expense and care were gone into in this study.

The author notes in Mr. Tuttle's remarks some points of extreme interest on the subject of steel pipes, but does not feel called upon to lengthen the discussion by adding to this branch of it.

It would have been tedious to have "gone a step farther and separated the cost of work done on a cash basis from that which was done when the company was known to be in financial straits," as Mr. Riffle suggests might have been done. There was no work of moment actually completed and measured up while the company was yet on a cash basis. The change was a gradual one, as the article clearly indicates. The suggested corrections for labor inefficiency are believed to afford a key for more detailed analysis of cost. The author would not have felt justified in going further into details and particulars.

"That the entire work could have been completed at a less cost to the company by an experienced and responsible contractor" does not "go almost without saying." This work was a novel one, from start to finish, except in the tunnel driving, pipe construction and canal excavation. These three classes of work were done under contracts by specialists of the very highest standing and with the best facilities. Those portions of the work which were done by the day could not have been contracted at any reasonable cost. The variety of construction was infinite, the pieces many, small and scattered. It would have been next to impossible to have specified beforehand just what was wanted. To have tied the work down to specifications would have sacrificed the value of results, or would have entailed endless bills for extras. The author does not admit that on this class of construction

there are any "experienced and responsible contractors," except in some of the separate specialties mentioned, who could better handle the work than the engineers who were in charge of it. If Mr. Riffle's remarks on this point apply to the unfortunate complications regarding the superintendence of common labor in this case, they are pertinent. Mr. Hall.

Mr. Riffle takes exception to the author's remarks on the cash system of employment for day labor and the absence of time checks, and in so doing he makes much more out of those remarks than was intended, and gives them a meaning they do not convey. The author said, in substance, and still believes, that a better class of men are held on works of this description and better results are had by not paying monthly in cash. The reasons are given in the paper.

Mr. Riffle implies that the author and the management would have been parties to a deliberate deception of the laborers, and he says that western engineers lend themselves to this practice. He has no ground for this stricture. Members are simply invited to read the last two paragraphs of his discussion, and then read the paragraphs of the article which have called them out. The author knows nothing of other examples mentioned by Mr. Riffle, and, hence, has nothing to say of them.